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SIX GREAT INVENTORS

JAMES WATT
GUGLIELMO MARCONI
GEORGE STEPHENSON
THE WRIGHT BROTHERS
THOMAS ALVA EDISON
FRANK WHITTLE

J. G. Crowther has described the lives, circumstances and inventions of six of the greatest inventors of the modern world. These men had the sensitive spirit of creation but were confronted with the problems of finance and production. It was only because they succeeded in dealing with these incongruous and antagonistic activities that they were able to provide mankind with the equipment of the modern age.

All of them had a struggle. They suffered agonies of thought, searching for elusive solutions. They experienced the mental depressions of repeated failures, besides the exaltations of occasional successes. They felt the anxieties of having their ideas appropriated, and wrestled with the problems of turning them to practical use. Yet in the end they triumphed over these difficulties and thereby increased the power and dignity of man.

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SIX GREAT INVENTORS

WATT · STEPHENSON · EDISON
MARCONI · WRIGHT BROTHERS
WHITTLE

BY

J. G. CROWTHER

> 'Whereas founders of states, lawgivers, extirpators of tyrants, fathers of the people, were honoured but with the titles of demigods, inventors were ever consecrated among the gods themselves.'
>
> Francois Bacon

HAMISH HAMILTON
LONDON

First published in Great Britain, 1954
by Hamish Hamilton Ltd
90 *Great Russell St London WC*1

Reprinted November, 1954
Second Impression, September, 1957
Third Impression, April 1960

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Class No. 926
Book No. C75 S9
Received on April 62

PRINTED IN GREAT BRITAIN
BY WESTERN PRINTING SERVICES LTD., BRISTOL

ACKNOWLEDGMENTS

THE main sources of information are given in the lists of references at the end of each chapter. The author acknowledges with gratitude his indebtedness to the authors of these works.

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FOREWORD

IT WAS observed a long time ago that necessity is the mother of invention. The need for mechanical power became overwhelming in the eighteenth century, so James Watt found how to supply it. Rapid transport became essential in the nineteenth century, and George Stephenson led those who provided it. The vast distances in the virgin continent of America stimulated the development of the electric telegraph, in which Edison began his life of invention. The need for instantaneous communication in one world prompted Marconi to invent wireless. Tiring of the speed of George Stephenson's trains, mankind desired wings, and the Wright brothers provided them. Even these proved too slow, and Whittle has begun to change mechanical birds into shooting stars.

The men who have had the leading part in achieving these changes were children of their times, besides being geniuses. When their life and work are looked at in the perspective of history, it is seen that their abilities and circumstances were peculiarly suited to the solution of contemporary problems, though this was often not immediately evident.

All of these great men had a rough struggle, and some a very rough one. Necessity has so far not been indulgent to her midwives, the inventors.

An inventor's life acquires its special interest because of his inventions. These therefore have a prominent place in his biography. For this reason, the form of the biography of an inventor is somewhat different from that of, for example, a statesman. The inventor deals with inventions, which are things, whereas the statesman deals with people. Things are consequently more prominent in his biography, whereas people are more prominent in the biography of the statesman.

The inventor is the symbol of human creative power in the realm of things. It is his achievements which give mankind the hope that all the possibilities of the material world shall be harnessed for the accomplishment of human aspirations.

For the purposes of this book, the Wright brothers have been regarded as one composite inventive personality. Their achievement was the result of mutual inspiration and discussion, and their respective contributions cannot be separated.

JAMES WATT

1736–1819

JAMES WATT, chief inventor of the steam engine, which first gave mankind the command of virtually unlimited power, was born at Greenock, near Glasgow, on 19 January 1736.

His ancestors were not well known, but they were persons of spirit and ability. They came from Aberdeenshire, where his great-grandfather, who had probably been a farmer, was killed in the religious wars, fighting for the Covenanters.

This great-grandfather left an orphan son, Thomas, who became a teacher of mathematics and navigation, and settled near Glasgow. A portrait of Thomas Watt exists, and shows him a man of lively intelligence and refinement. Like his father, he was a man of principle. Because of his Covenanter's views, he was at one time proclaimed 'a disorderly schoolmaster officiating contrary to law'. Nevertheless, he rose to be a local magistrate and elder of the kirk.

His son James, James Watt's father, had a shipwright's and general marine business at Greenock. His establishment contained a repairing shop, tools, navigational instruments, and stores for ships' supplies. He was the first to erect a crane in Greenock.

In the earlier part of his life he was quite prosperous and even owned small ships. These were engaged in the tobacco trade with Virginia.

He had inherited from his mathematical father pictures of Napier and Isaac Newton, which he hung in his home. His son James, who became the greatest of inventors, grew up with these pictures, and from his earliest boyhood could remember the eyes of Napier and Newton gazing at him out of their frames.

James Watt senior married the sister of his business partner, John Muirhead. This lady, the mother of the inventor, was an impressive woman who was considered to live in a rather superior style. Her kinsman George Muirhead was professor of Latin at Glasgow University, and joint editor of Foulis' great four-volume folio Homer, the favourite edition and constant companion of Gibbon and Winckelmann.

Her son James was a delicate child, suffering from severe sick headaches, probably a kind of migraine. This affliction made him shy, and he shrank from the rough company of the boys of the neighbourhood. Throughout his life James Watt suffered from these terrible headaches, often having three in a week. They had a profound effect on his temperament and character.

As a delicate child his attendance at school was irregular, and his parents taught him reading, writing, and arithmetic. He showed a retentive memory and an interest in learning, and was encouraged to work at home. His father gave him a specially made set of small carpenter's tools, which he used with intense pleasure. He was reared with unusual understanding, being encouraged when he showed initiative, and not driven when he was ill and depressed.

He became fond of reading, and before he was fifteen years old, he had read through S'Gravesande's *Elements of Natural Philosophy* twice. He spent much time in Glasgow with the Muirheads. They lent him books and introduced him to well-educated undergraduates. He became deeply interested in anatomy, and retained this interest for the rest of his life. He said that he would have liked to become a surgeon, but could not, because he was unable to bear the sight of suffering.

In addition to his work at home he received some casual schooling in Latin, mathematics, and commercial subjects. His mathematics teacher was John Marr, who, like Watt's grandfather, was a teacher of navigation. He became interested in geometry, and learned to be a fine draughtsman. To the end of his life he made beautiful engineering drawings.

As he grew older he spent more and more time in his father's workshops, helping with carpentry, metal-working, the repair of navigational instruments, and book-keeping. He used the instruments to observe the stars. He was naturally qualifying to succeed to the family business.

And then his father lost a valuable ship at sea. His business declined, and presently he found himself in financial straits. It became evident that there would be no business for James to inherit, and that he would have to seek employment. The boy passionately desired to be a mathematical instrument maker, and his parents approved his choice.

It had never been intended that James should be a workman, and he had not been apprenticed to a trade. Nor had he been regularly educated in preparation for a profession or entrance to a university. He was now eighteen years old, and neither a workman nor a student.

As there was no one in the village of Greenock who could teach him instrument-making, he was sent to stay with the Muirheads, his relations in Glasgow, to give him an opportunity to find a master in the city. At that time, however, Glasgow was still primarily a university town. It was as yet only a minor port. The river was full of shoals, and would not take ships of more than ten tons burthen. When James Watt arrived in 1754, the annual harbour dues were only £8; a century later they were £86,580.

He could not find anyone in Glasgow to teach him instrument-making, so the Muirheads introduced him to Robert Dick, the professor of natural philosophy, ~~or physics,~~ in the university. Dick advised him to go to London, and gave him an introduction to James Short, a well-known instrument-maker.

James Watt set off to London in 1755, with the son of the Greenock schoolmaster who had taught him geometry. They travelled by horseback on roads pestered with highwaymen, but arrived in London safely. James wrote home, while passing through Yorkshire, that he liked 'the country very well', but thought that 'the people are very sharp'.

He found life in London dangerous. The Government had been experiencing serious defeats in the colonial wars, and the press gangs were more active than ever, catching men on the streets and forcing them into service as new naval crews. Even worse, men were being kidnapped and shipped off to work in the plantations, from which they rarely returned.

James had to keep indoors as much as possible to avoid being carried off.

As he did not belong to London, he was not qualified to join a London guild of craftsmen, and become a regular apprentice. Short would not take him, but recommended him to John Morgan, who, for a fee of twenty guineas, agreed to have him in his shop for one year.

James was put to work in a draughty spot, where he laboured with tools for ten hours a day, going to bed with 'his hand shaking'. He was assailed by 'violent rheumatism, a gnawing pain in his back, and weariness all over his body', through overwork, and lack of fresh air and healthy exercise.

But he made great progress in the craft. At the end of the year he was able to make first-class instruments, though not so quickly as the best men with long experience. He returned to Greenock, and after two months' rest at home in his native air, he recovered his usual health.

Watt now sought employment as an instrument-maker in Glasgow. According to Black, he was warned by the guild to which instrument-makers belonged, that he must not practise the craft in the city, as he was not one of their members. However, every effort to find any further evidence in confirmation of this story has so far failed, and it may well be that Watt's fear, with his timid disposition, that it might happen led to the belief that it actually did.

Whatever the cause, he did not find employment in the city, and again he was helped by Professor Dick. The university had received a large bequest of fine apparatus from Alexander Macfarlane, a wealthy merchant who had built a private observatory on his estate in Jamaica. On the motion of Dick, Watt was engaged by the university to clean these instruments and put them in working order. He did this satisfactorily. His academic friends now persuaded the university to give him a workroom and lodging within its precincts, together with the title of Mathematical Instrument Maker to the University. The charter granted by the Pope in 1451 had given the university absolute authority within the area of its buildings, so Watt was now beyond the jurisdiction of the guilds.

The collection of instruments, and presently Watt himself, attracted many of the most active spirits in the university. His workshop became an informal meeting-place for the scientists. Robison, then a seventeen-year-old undergraduate, used to spend much of his time there. He has described how Professor Joseph Black, elegant in mind, manner, and appearance, the discoverer of carbon dioxide, of latent and specific heats, the foremost chemist in Europe before Lavoisier, 'used to come in, and, standing with his back to us, amuse himself with Bird's quadrant, whistling to himself, in a manner that thrilled me to the heart'.

Robison subsequently joined the Navy as a navigation officer. He was on duty in the boat in which Wolfe visited his posts before storming Quebec, and it was he who reported that Wolfe recited Gray's *Elegy* as they rowed along the river, and said he would rather have written that poem than have the glory of victory on the morrow. Robison took part in the testing of Harrison's chronometer at sea. He became director of the Imperial Marine Academy at St. Petersburg, and finally professor of natural philosophy at Edinburgh.

Dick had been succeeded as professor of natural philosophy at Glasgow by John Anderson, formerly the professor of Hebrew; another striking character, who insisted on artisans being allowed to attend his lectures in their working clothes. Many years later he offered a cannon he had invented to the French National Convention, after it had been rejected by the British Government. Anderson gave Watt the free run of his library.

At this time, in 1757, Adam Smith was professor of moral sciences, and very active in the management of the university. It is almost certain that the founder of political economy had a part in the appointment of Watt as instrument-maker to the university, and was well acquainted with Watt's activities. But, as Fay has remarked, it is interesting to note that the word 'steam' does not occur in the *Wealth of Nations*.

The Glasgow professors at this time were not only great, but young. In 1757, Black was only twenty-nine, and Adam Smith thirty-four. It was from the *Wealth of Nations* that William Pitt gained, as a student at Cambridge, the understanding of economics which enabled him to become the spokesman of the new rulers brought forth by the Industrial Revolution, and prime minister at the age of twenty-four.

The brilliance of Glasgow University when Watt became its Instrument Maker was, no doubt, a reflection of the special character of the national religious and educational system, which had been forged in the Scottish people's struggles for freedom.

John Knox himself had proclaimed that 'no father, of what estate or condition that ever he may be, use children at his own fantasie, especially in their youthhood, but all must be compelled to bring up their children in learning and virtue'. He demanded that there should be a school in every parish in Scotland. He intended to have a competent and well-educated army of supporters. The parish ministers and schoolmasters, elected by the local congregations, were in a considerable degree the democratically-elected officers of this army. Vigorous universities were required to give them the higher training. Glasgow University had about three hundred students, and most of them were intended for the ministry. About one-third were Irish Presbyterians or Ulstermen.

James Watt, a youth in the early twenties, neither a graduate of the university nor a qualified craftsman, was accepted with a striking absence of snobbery by several of the most eminent men in intellectual history.

Black has written that soon after Watt was appointed instrument-maker, he had occasion to employ him to make some things for his experiments and 'found him to be a young man possessing most uncommon talents for mechanical knowledge and practice, with an originality, readiness, and copiousness of invention, which often surprized and delighted me in our frequent conversations together'.

Watt said that Robison had the quickest and clearest comprehension of every question in science of any person he ever knew, and added to that a very pleasing manner of explaining it to others. Robison remarked that as soon as Watt had understood an explanation his mind struck at once 'into untrodden paths', where he, Robison, 'was always obliged to be a follower'.

The contrast between the minds of Robison and Watt provides a fine illustration of the difference between scientific ability and inventive genius. In his last years, Robison referred to the 'careless days and gay scenes' in the instrument-maker's workshop, and raised in the imagination a vivid picture of the talented and enthusiastic young men at Glasgow, who were finding the way to the modern age.

Robison drew Watt's attention to steam engines some time before 1759. He discussed the possibility of applying them to the driving of wheeled carriages, and Watt made a model to try out their ideas, but it was unsatisfactory. Two years later, Watt made some experiments with a small syringe, containing a piston, after the manner of Papin. He lifted considerable weights attached to the piston by letting steam at high pressure into the syringe. He did not pursue the principle because of the danger of explosions, and other mechanical difficulties, but he subsequently patented it in 1769, and its application to wheeled carriages in 1784. He had thus patented the high-pressure steam engine and locomotive, though he never developed them.

Watt's income as Instrument Maker to the University was insufficient to live on, so he opened a shop in Glasgow in partnership with a friend, for selling instruments and metal objects, such as buckles. He engaged in the making of pottery, which later gave him a common interest with Josiah Wedgwood.

These strenuous efforts enabled him to support a wife, and in 1764 he married his cousin Margaret Miller. They settled in a very modest house near the pottery.

Margaret Miller had a sweet temper and cheerful disposition. She greatly helped her gifted husband to combat the effects of his severe attacks of migraine. These caused profound depression and intense feelings of failure, and cast him into a state of melancholy inactivity. She was able to appeal to his natural gentleness and affection, and rouse him from these fits, and get his genius working again.

Towards the end of 1763, Professor Anderson requested Watt to repair a model Newcomen engine which belonged to his department. It would not work, and it was to be put into running order, so that it could be used in the lecture demonstrations to students.

Newcomen's engine had been invented about 1702, for pumping water out of tin- and coal-mines. The coal production of Britain was expanding rapidly, and was then about six times that of the whole of continental Europe. Mines were getting deeper, and flooding was becoming more and more serious. Newcomen's engine was the first effective machine for using the energy of heat from coal for removing water from pits. It consisted of a big cylinder containing a piston, whose top was exposed to the atmosphere. The air inside the cylinder under the piston was blown away by steam, and then the steam was condensed by injecting cold water into the cylinder, producing a vacuum under the piston. The pressure of the atmosphere on the top of the piston then pushed it down, thereby operating the beam of a pump. Newcomen's piston was essentially the replacement of the human hand by mechanical power, the beam of his engine corresponding to the handle of an ordinary hand-pump.

As his engine needed only inferior coal, available in quantity at the pit-head, and almost valueless for any other purpose, its heavy consumption for power produced was for a long time not felt to be a serious drawback. For this reason, the engine, though a great invention, developed slowly during the next fifty years.

The work of the Newcomen engine was done by the pressure of the atmosphere, not by the pressure of the steam. It was therefore not, strictly speaking, a steam engine, but an atmospheric engine.

The engine which Watt was requested to repair was a small-scale model, the size of cylinder and boiler being reduced in equal proportion to those in the full-size engine. When he put water in the boiler of the model and got up steam, he could not make the engine perform more than four or five strokes. He varied the arrangements until he got it to run continuously.

But unlike a 'mere mechanician' as he put it, he did not remain satisfied with having got the engine to work. That was not good enough. He plunged into an analysis of the principles of the engine. He asked himself not only why it had not worked, but by precisely how much it had failed to work.

At that time, Watt was not an engineer. He had had no experience in building and operating Newcomen pumping engines. He did not bring to the problem the attitude of the contemporary practical man who was satisfied with making a machine work. Nor was he a scientist, interested primarily in the theory of its operation.

His lack of membership of a guild of craftsmen, and lack of a university education, which had appeared to be two misfortunes, now helped him to avoid looking at the engine from either of the old points of view, and to find a new way of investigating it. This consisted of a combined scientific-and-practical analysis of how it worked. It is the characteristic method of modern engineering. Watt contributed more than any other man to the development of this way of thinking, and is entitled to be regarded as the first modern engineer.

He began by seeking for an explanation of why the scale model used proportionately so much more steam than the full-size engine. One reason was that in a small cylinder the ratio of inside surface area to volume is much greater than in a big cylinder of similar shape. Because of this, the inside surface area through which the heat of the steam could escape was comparatively much larger in the small model than in the big engine.

Watt turned from the practical man's concern with the consumption of those concrete things, steam and fuel, to the movement in the engine of the scientist's abstract entity, heat. He began to study the transferences of heat in each of the engine's operations.

He noted that the cylinder of the model was made of brass, whereas that of the full-size engine was made of cast iron. As heat could escape through brass more easily than through cast iron, it was evident that another contributory cause of the model's failure was the use of brass for the cylinder. He substituted a cylinder made of wood, but even with the poorly-conducting wood the model was still consuming too much steam.

He tried to improve the vacuum in the cylinder by throwing in more cold water. But this cooled the cylinder so much that a large amount of steam was needed on the next stroke to warm it up again, so that the steam could persist in the cylinder and lift up the piston.

It was evident that there would be a great gain of efficiency if the cylinder could be kept permanently hot, and that, somehow or other, condensation for producing a vacuum could be obtained without alternate heating and cooling.

This was a profound discovery, but Watt's method of attaining it was even more remarkable than the fact itself. In his analysis of what happened in the Newcomen cylinder, he made use of the phenomenon of boiling of water under reduced pressure, recently discovered by William Cullen, who was Black's teacher. He made an experimental investigation of the effect of temperature and pressure on the boiling-point of water, and plotted his results on a curve, which he used to guide him in his choice of temperature and pressure at which the engine should run.

He measured the volume of steam produced by boiling a given quantity of water, and found that it was 1,800 times as great. He made a special boiler which enabled him to measure exactly the rate at which water was evaporated, and thus the rate at which steam was supplied to the engine. He combined all this originally-discovered knowledge to elucidate exactly what happened inside the engine, and he proved that in each stroke the volume of steam consumed was several times the volume of the cylinder. This seemed an astounding paradox.

He had been astonished by the small amount of steam which was necessary to raise the temperature of the cold water injected into the cylinder to a high degree. He found, in fact, that 'water converted into steam can heat about six times its own weight' of cold water up to boiling-point.

He mentioned this extraordinary result to Black, who then explained it to him in terms of his own discovery of latent heat, the extra energy needed in order to produce a change of state, from liquid to gas.

No research of this degree of experimental and abstract theoretical difficulty had before been seen in the history of engineering research. Yet, in spite of his brilliant discovery of the cause and the degree of the inefficiency of the Newcomen engine, Watt had not yet the slightest idea of how it could be avoided. So far, in this work, he was primarily a scientific engineer: he was not yet the inventive engineering genius.

Watt struggled with the apparently insoluble enigma of how the condensation of the steam could be conducted outside the cylinder for two years before he found the solution. He wrestled with it in agonizing thought, and made many experiments. Then, one day, the idea flashed into his mind.

'It was in the Green of Glasgow. I had gone to take a walk on a fine Sabbath afternoon. I had entered the Green by the gate at the foot of Charlotte Street—had passed the old washing-house. I was thinking upon the engine . . . and gone as far as the Herd's House when the idea came into my mind that as steam was an elastic body it would rush into a vacuum, and if a communication was made between the cylinder and an exhausted vessel, it would rush into it and might be there condensed without cooling the cylinder. I then saw that I must get quit of the condensed steam and injection water, if I used a jet as in a Newcomen's engine. Two ways of doing this occurred to me. . . . I had not walked further than the Golf-house when the whole thing was arranged in my mind.'

As Black put it, this capital improvement filled Watt with rapture. Watt's solution of the condensing problem by taking it out of the cylinder and putting it into a separate condenser is the most important of all inventions. Besides starting the continuous improvement of the steam engine, and thereby bringing unlimited steam power within the prospect of mankind, it began the era of mechanical progress based on the utilization of abstract scientific knowledge by systematic engineering invention.

Like Faraday's discovery of how to obtain electricity from magnetism, it has a deceptive simplicity, but was in fact arrived at only through the aid of highly abstract ideas, and new physical measurements, quite beyond the range of contemporary practice.

After gaining the idea, Watt swiftly constructed the new engine in his imagination. Leaks round the piston and cylinder in the Newcomen engine were sealed by covering the top with water. This could not be done if the cylinder was kept hot. He therefore decided to close the top of the cylinder and cover the piston with steam, and use the pressure of the steam, and not that of the atmosphere, to force the piston down.

Thus in his imagination he converted the Newcomen atmospheric engine into a steam engine. The new engine, he knew from his previous experiments, would be about four times as efficient as the old. 'All of this passed in his mind in the course of a few hours; and in a few days he had a model at work. . . .' This is now in the Science Museum in London. It is put together out of odds and ends, including one of his wife's thimbles.

Robison described how he happened to walk 'without ceremony' into Watt's parlour at this time, to mention an idea he had had about steam engines. Watt was sitting in front of his fire, with a 'little tin cistern' on his knee. In reply to Robison he said: 'You need not fash yourself any more about that, man; I have now made an engine that shall not waste a particle of steam.' Robison asked about the principle, but Watt evaded answering him. He looked at the other part of the machine which was on the floor with a complacent expression, and pushed it under the table with his foot. During the next few days, Robison elicited the principle of the invention, without revealing his own ignorance of it, by discreet cross-questioning of Watt's other friends.

Watt now tried to construct a full-size engine for practical work. This would have seemed to have been relatively easy, but it turned out to be very difficult. Up to this time Watt had had no experience of making big machines. When he tried to make a big engine, he found himself beset by a multitude of new problems of a mechanical nature. One of the most difficult was the packing of the piston so that it would slide easily, and yet not allow the steam to leak past. It took him several years to find a satisfactory solution. He tried all kinds of things, and reported that he had found by experiment that for making joints steam-tight there was nothing equal to 'a mixture of pasteboard, cork, tow, and horse-dung'.

He was recurrently assaulted by attacks of migraine which plunged him into melancholy and despair. These often preceded the birth of his best ideas, but their immediate effect was to leave him feeble and inert.

He had no capital for financing his experiments, which were now costing much more because they were on a larger scale. He gradually borrowed the substantial sum of £1,200 from Black, in order to pursue them. His temperament, combined with his Scottish tradition of thrift, caused him to suffer paroxysms of anxiety over his debts.

Mary Anne Galton subsequently described him as a most complete specimen of the melancholy type. 'His head was generally bent forward or leaning on his hand in meditation; his shoulders stooping and his chest falling in, his limbs lank and unmuscular, and his complexion sallow.' He spoke in a quiet voice, low and deep in tone, with a broad Scottish accent. He was contemplative, and had an extraordinary store of unusual information. In his later years, when a celebrated Swedish artist was introduced to him, he immediately told the artist that 'rats' whiskers make the most pliant painting brushes'.

His young wife bravely encouraged him through his sick-headaches, depressions and difficulties. In 1768, she wrote to him: 'I beg you would not make yourself uneasy, though things should not succeed to your wish. If it [the new steam engine] will not do, something else will. Never despair.'

Black recommended Watt to his old pupil Dr. John Roebuck for financial suport. Roebuck had practised medicine in Birmingham, and had invented the lead chamber process for making sulphuric acid. By industrializing the production of this primary chemical, he enormously reduced its price, and made a large fortune for himself. He used his wealth to build a new iron-works in Scotland, on a rational plan. He chose a site beside the River Carron, where it runs into the Firth of Forth. There were excellent local supplies of iron ore, limestone, water, and transport, and the equipment was designed by John Smeaton, the most famous engineer of the day. The new iron-works made the improved cannon called 'carronades', which were very destructive against wooden ships, and greatly increased the striking-power of the British men-of-war.

Roebuck sank new pits to provide coal for his works, but was troubled by serious flooding. He was consequently keenly interested in pumping-engines. As a scientific industrialist, financing technical developments was not strange to him. He enthusiastically adopted Black's suggestion that he should encourage Watt, and the construction of an engine on the new principle was begun at Carron in 1765. It made slow progress. The Carron works was equipped for smelting and casting, rather than machine-making. The parts for the new engine were very roughly made, and Watt could not make them work satisfactorily. He suffered agonies of worry.

He engaged in routine surveying, to increase his income and distract his mind. 'Hire yourself for a ploughman; it will cure ennui,' he wrote. He surveyed the land for a new canal for the Carron company. He had to go to London in 1767 to give evidence on the project to a committee of the House of Commons. He wrote to his wife that he hoped he would never have anything to do with the place again: 'I never saw so many wrong-headed people on all sides gathered together.' He did not know at the time, however, how fortunate his journey was to prove.

It seems that Roebuck advised him to call at Birmingham on his way, and gave him introductions to his old friends in the brilliant group of men associated with the progressive industrial magnate, Matthew Boulton. When Watt called, Boulton was away, but he was received by Dr. William Small, Boulton's Scottish friend.

Small had been professor in Williamsburg, Virginia, where he had taught Thomas Jefferson, and inspired him with a love of science. Jefferson wrote in his autobiography that Small 'probably fixed the destinies of my life'. Small returned to England because of bad health. Benjamin Franklin gave him a letter of introduction to Boulton. He settled in Birmingham and became one of Boulton's closest friends and scientific advisers.

Small had wide scientific interests and a sympathetic, stimulating character. He and Watt soon became intimate friends, and he had a great part in 'fixing the destinies' of

Watt's life, as well as Jefferson's. The scientific advice that he gave Watt was not very good, but he was able to give him stronger psychological support than he received from any other man in this critical period of his life.

Watt also made the acquaintance of Erasmus Darwin, the grandfather of Charles Darwin. He revealed to him in strict secrecy his great invention, and also, it seems, something of his temperament, for very soon afterwards the wise old doctor wrote to him: 'Now, my dear new friend, I first hope you are well and less hypochondriacal....'

By 1768, Watt had constructed a small engine on his new principle. Roebuck was favourably impressed, and decided to take over two-thirds of the rights in it, and to relieve Watt of his considerable debt to Black.

Later in the year, Watt visited Birmingham again, and met Boulton. The two utterly dissimilar men took to each other at once. Watt was despondent, timorous, original, profound, hypercritical, suffering agonies over decisions, terrified of business negotiations to an almost tragi-comical degree. Boulton was cheerful and confident, and a brilliant man of affairs. He had married an heiress, and expanded the family business in the making of Birmingham metalware. This Birmingham trade was already large, and notorious for its flashiness. Boulton set out to improve the organization of the handicraft manufacture and raise the æsthetic standard of the goods. He built a big factory at Soho near Birmingham, in which the craftsmen were provided with the finest tools available, and the subdivision of handicraft labour was worked out to a further degree, laying the foundation for the introduction of methods of mass-production.

Boulton himself was no mean inventor. He took Watt around the works, whose improved wares were being exported over all Europe. Watt noted seeing: 'steel, gilt, and fancy buttons, steel watch-chains and sword hilts, plated wares, ornamental works in ormolu, tortoise shell.... I was informed that Mr. Boulton was the first inventor of the inlaid buttons, and the first who applied a mill to turn the laps. . . .'

Watt saw the kind of skill and tools which were lacking at Carron, and which were necessary for making a really good engine. Boulton's combination of business and technical ability with scientific and cultural interests was the perfect complement to Watt's profound inventive genius and timorous character.

Boulton gloried in social occasions, while Watt shrank from them. He called his home the 'Hôtel d'Amitié sur Handsworth Heath'. The Boulton tradition continued after he had died. When the Grand Duke Nicholas, the future Tzar, and suppressor of the Decembrist rising of 1825, visited England in 1816, he applied, with a supporting letter from Lord Sidmouth, for permission to visit the works. This was refused, not from any objection to the young man himself, but because of a suspicion that some of the persons in his entourage were looking out for industrial secrets.

In later years, Boulton became deeply interested in the minting of coins. He improved the technique, and introduced the use of the steam engine for driving the machinery. He secured big contracts for recoining the money of several countries. Consequently, he had from time to time large stocks of gold at his works.

On one occasion, a gang of burglars organized a raid on these stocks. They offered a bribe of £100 to the nightwatchman to open all of the patent locks, and make himself scarce. He reported the offer to Boulton, who told him to pocket the money, and leave the locks unfastened. He would himself organize a reception for the desperadoes. Sir Walter Scott has left an account, not entirely accurate, of what happened.

'Midnight came,—the gates opened as if by magic,—the interior doors, secured by patent locks, opened as of their own accord,—and three men with dark lanterns entered and went straight to the gold. Boulton had prepared some flax steeped in turpentine,—he dropt fire upon it, a sudden light filled all the place, and with his assistants he rushed forward on the robbers;—the leader saw in a moment he was betrayed, turned on the porter, and shooting him dead, burst through all obstruction, and with an ingot of gold in his hand, scaled the wall and escaped.'

Scott based his scene between Meg Merrilies and Dirk Hatteraick in the cavern in *Guy Mannering* on this incident. 'I like Boulton,' he said, 'he is a brave man, and who can dislike the brave?'

Watt wrote that the works' 'young men were commanders-in-chief', and fell on the burglars as they emerged 'with guns, pistols, bayonets, and cutlasses'.

Boulton pensioned the betraying night-watchman, who was wounded but not killed. He had to go into hiding, even from his wife.

This was not the only occasion when Boulton organized his private bodyguard. In 1780 the great radical clergyman and chemist, Joseph Priestley, settled in Birmingham. Boulton and his circle of friends welcomed him warmly. He became a leading member of their society, which met every month to dine together and discuss the latest scientific news. They chose the night of the full moon, in order to have the benefit of its light in finding their way home in the early hours.

During the French Revolution, Priestley was elected an honorary deputy of the National Convention. In 1791 he and other Birmingham friends of the Revolution dined in celebration of the fall of the Bastille; in the opinion of Watt, 'very foolishly'. Rioters were instigated to attack the hotel where the dinner was held. They went on to set fire to dissenters' houses, and razed Priestley's home, containing his books and chemical apparatus, to the ground. 'Our principles', wrote Watt, 'are well-known, as friends to the established government, and enemies to republican principles, and should have been our protection from a mob whose watchword was Church and King.' But this was not so. Boulton found it necessary to barricade his premises, and arm his workmen as a precaution.

In spite of being a friend of established government, Boulton immediately began organizing the subscription of a pension for Priestley, and Watt wrote to Priestley expressing his 'abhorrence of the motives which instigated the perpetration of these atrocious insults to all laws, both divine and human', especially as he 'had reason to believe myself among your other friends, was included in the proscription'.

Poor Watt was to have another anxious period in the following year. He had sent his son James Watt junior to Geneva to be educated. On his return in 1788, Watt placed him in a Manchester printing and bleaching firm. He became friendly with the wealthy bleacher Thomas Cooper, who was keenly interested in politics, and a passionate admirer of the French Revolution. The Constitutional Society of Manchester deputed Cooper and James Watt junior to present an address to the Société des Amis de la Constitution. They arrived in Paris in 1792, and became involved in the revolutionary struggles.

According to Southey, 'Danton and Robespierre quarrelled at one of the political clubs . . . high words ending in a challenge: they met, and the duel was prevented by the interference of an Englishman, who went out as a second to the one, and represented to them how injurious it would be to the cause of liberty if either of them should fall. . . .'

The Englishman was young James Watt. Burke heard about it, and thundered in the Commons that Watt and his friend Cooper 'had presented an address, and carried the British colours in a procession; and on what occasion? The most infamous that ever disgraced the name of government. A set of soldiers had been tried by a court-martial, and condemned to the galleys. These were fit men for the republicans of Paris. They might be useful:—though bad soldiers, they might be good murderers. They were released in contempt of the Assembly then sitting; brought to Paris, and paraded in triumph through the hall. On this detestable occasion, Mr. Cooper and Mr. Watt carried the British colours. They were locked in the fraternizing embrace. They received the fraternizing kiss. They went from the hall of the Assembly to the hall of the Jacobins, where they kissed the bloody cheek of Marat....'

Wordsworth has recorded that when he arrived in Paris at this time, he found young James Watt already there. Young Watt was presently warned that Robespierre suspected he was an agent of Pitt (Boulton and James Watt senior in their visits to France before the Revolution had always called on Pitt, either before or after their journey), so James Watt junior fled into Italy as quickly as possible, and did not return to England until 1794. In later life, he settled down, together with Boulton's son, as a successful proprietor and manager of the famous firm.

But these things were in the future, and it is necessary to return to 1767.

Boulton, Small, Darwin, and their circle were already keenly interested in engines. The growth of Boulton's factory had increased the demand for power for many of the manufacturing operations. He used a water-wheel, but this was increasingly unsatisfactory, owing to the limited amount of power obtained from it, and its liability to stop and halt the flow of production, when the stream ran low in dry seasons. Like other industrialists, Boulton hankered after a pumping-engine which would pump the same quantity of water over and over the water-wheel, and keep it going steadily through droughts. Small and Darwin were alert to any kind of scientific fancy which bore on this problem, and Boulton drew on them as a bank of scientific ideas and imagination for giving him hints which might be of industrial value. All of them at once perceived the scientific and industrial importance of Watt's invention, and Boulton expressed the desire to acquire a share in it.

Watt returned home from his call on them greatly encouraged, and gave the news to Roebuck, which stimulated interest in the engine. Watt applied for a patent for the separate condenser, and received it in January 1769. He was advised by Small and Boulton in drafting it. Experience subsequently proved their advice had not been sagacious. They told him to patent the principle, and give as few drawings and precise details as possible. Their idea was to hinder imitators. Watt had more wisely prepared detailed drawings, but followed their advice and withheld them. The bad drafting of the great patent subsequently much increased the difficulty of defending it against infringers.

Watt told Roebuck of Boulton's desire to acquire a share in the patent, but Roebuck offered him merely the right to manufacture the engine in three counties. Watt had not told Boulton that Roebuck had the controlling interest, and he now wrote to him explaining the situation, so that he would understand why he had not been offered a share in the engine.

Boulton was justifiably surprised by Watt's letter, and Roebuck's inadequate offer. He replied most brilliantly to Watt. He said that the plan which was now proposed to him was so very different from that which he had conceived when he had discussed the subject with him that he thought he had better not pursue it, for he had no intention of becoming merely an engineer. Two motives had excited him to consider the plan: 'love of you and love of a money-getting ingenious project'. He presumed that the engine would require finance, accurate workmanship, and a good selling organization to make it a success, and it would be necessary to keep its execution out of the hands of 'the multitude of empirical engineers' if its reputation were to be maintained. His idea had been to establish a special engine factory near to his existing works fitted with all the equipment necessary for the completion of the engines. From this factory 'we would serve all the world with engines of all sizes'. Workmen would be specially trained for this new branch of engineering, and expensive tools installed, which would enable the engines to be made '20 per cent cheaper', and with as great difference in accuracy of workmanship as there is between a blacksmith and a mathematical instrument-maker. 'It would not be worth my while to make for three counties only, but I find it very well worth my while to make for all the world.' No wonder Boulton subsequently told Boswell that he sold what all men desire—power.

He had dropped the hint that he would like a share in the engine because he conceived the notion that Watt wanted a midwife to ease him of his burthen. He would never have dreamt of doing this if he had known of Watt's pre-engagement to Roebuck, for he was determined never to embark on any trade in which he had no share of the control. He felt he would have to—no, he would leave Watt to draw the conclusion. Nothing would alter his desire for a partnership with him, and he would live in hope that some way might yet be found of overcoming obstructions to it.

This masterly letter made Watt desperately keen to secure Boulton's participation. But progress was slow. Watt was forced to continue to eke out his living by surveying. His friend Robison went to Russia in 1770, and sounded Watt *as to whether he would accept the position of Master* Founder of Iron Ordnance to Catherine the Great. Watt turned the offer down, in spite of his poverty. In these difficult days, he received unfailing sympathy from Small, and from Josiah Wedgwood who suffered from similar delicate health and sensitive temperament.

Then, in 1772, there was a severe industrial depression.

Roebuck became insolvent, and even Boulton was in difficulties. Watt was almost beside himself. He wrote to Small imploring him to persuade Boulton to take over Roebuck's rights in the engine; 'everything has been turned over upon me, and the necessary clerks grudged to me; I am also indolent and fearful, terrifyed to make bargains, and I hate to settle accounts . . . a man is always disgraced by taking upon him an employment he is unfit for. . . . I can on no account have anything to do with workmen, cash, or workmen's accounts. . . . I have no great experience and am not enterprizing, seldom chusing to attempt things that are both great and new. . . . I am not a man of regularity in Business and have bad health. . . . I cannot forgive you writing me so seldom. . . .'

Incidentally, with a casual drawing in one of his letters to Small, he invented the screw propeller for ships. During his surveying labours to keep the wolf from the door, and cure 'ennui', he invented an optical range-finder for measuring distances.

Roebuck's creditors did not value the experimental engine at one farthing. Quite apart from the engine, Boulton was one of Roebuck's creditors. He made Watt his attorney in the insolvency proceedings, and ensured that the engine became Watt's property. It was immediately dismantled and sent to Birmingham. Boulton secured Roebuck's rights.

While this mixture of disaster and good fortune was proceeding, Watt was toiling away on a survey at Fort William, in terrible weather. He received news that his wife was dangerously ill. He began the rough journey home. When he came to Dumbarton, he had a presentiment that his wife was dead. A friend met him with the dreadful news that she had died in giving birth to a still-born child. Watt was left with two young children. 'Come to me as soon as you can', wrote his understanding friend, Dr. Small. There was nothing left to retain him in Scotland, and he moved to Birmingham in 1774.

Watt was now thirty-eight, and still had not made one engine for industrial use. But he was living in inspiring times. In 1774 Priestley discovered oxygen, and Scheele chlorine. Watt subsequently persuaded the father of his second wife, Ann MacGregor, to introduce Berthollet's invention of chlorine bleaching into Britain. Charles Tennant of Glasgow made this practical by his invention of bleaching powder. The time for bleaching raw cloth was reduced from six months to a few hours.

The meteoric Lancashire cotton industry was expanding at a tremendous pace, through a galaxy of inventions. The cotton magnates needed engines to drive their new machinery. Boulton presently wrote to Watt that 'the people in London, Manchester and Birmingham are steam mill mad'.

On the very day that Boulton wrote this letter, Watt wrote to Boulton, in agonies over having executed a mortgage to help him, that his 'sensations were such as not to be envied by any man who goes to death in a just cause. . . . I thought I was resigning in one hour the fruits of the labour of my whole life—and that if any accident befell you or me I should have left a wife and children destitute of the means of subsistence, by throwing away the only jewel Fortune has presented me with. . . .'

This was too much for even the resilient Boulton, who wrote to his financial agent in London, that by the same rule that Watt talked about his wife and children, he ought not to neglect his. Watt's fortune and his wife's together had not provided sixpence, whereas his own wife had brought him £28,000 in capital. He had advanced Watt all he wanted without security, but in return he is not satisfied with an ample security for advancing nothing at all.

But Boulton, remembering the brilliant signs of industrial development, ignored Watt's pessimism, and cheerfully bore his almost unparelleled complaining. He had even to help him with his second marriage. Watt needed a wife to look after himself, his family and his house. He sought the hand of Ann, the competent daughter of Mr. MacGregor, a dour Glasgow dyer. Before he would bestow his daughter on him, he demanded to see the partnership agreement between Watt and Boulton. Watt was in a fix. Such was the complete understanding and trust between the two men, that they had forgotten to make any formal agreement. Watt wrote to Boulton that he must 'get a legal contract written and signed by yourself, sent by return of post or as soon as may be'. Lest Mr. MacGregor should have called his prudence in question, he had 'been obliged to allow him to suppose such a deed did exist. . . .'

Boulton dealt with the situation in his usual masterly way. He sent a letter to be shown to Mr. MacGregor in which it was explained that he would most gladly have sent the document, but unfortunately 'Mr. Dadley, the lawyer, is suddenly called to London, and it cannot be had before his return', but if he wanted to show it to any of his friends, he could give them a copy of the list of points which he had extracted from their mutual correspondence, and which to the best of his knowledge covered all the main points on which they had agreed.

Mr. MacGregor expressed himself as satisfied.

Ann MacGregor was a capable wife, but does not seem to have had the charm of Margaret Miller. She bore James Watt three children, and two of these, Jessy and Gregory, died of consumption. Gregory lived to the age of twenty-seven, and showed fine scientific gifts before his premature death. His father was particularly attached to him.

The frequency of tuberculosis, even in relatively prosperous families such as the Watts, who included several of the most famous doctors of the day among their personal friends, is a striking illustration of the widespread ravages of the terrible disease in those days.

The affliction of his young daughter raised Watt's interest in the treatment of consumption, and he thought a cure might be found by inhalation of the newly-discovered gases. He contributed to the support of Beddoe's Pneumatic Institution at Bristol, founded for the treatment of disease by the inhalation of gases.

Watt sent Gregory to Cornwall for his health, and it happened that he found lodgings with the widow Davy, whose boy Humphry was one year Gregory's junior. Humphry Davy and Gregory Watt became close friends, and Beddoes presently offered Davy a post as research assistant in his institution. It was there that Davy discovered 'laughing-gas', the first anæsthetic.

Soon after Watt settled at Birmingham, Boulton had a bill presented to the House of Commons for the extension of the original patent for a further twenty-five years. Progress had been very slow, and there was a danger that the patent would run out before the new engine had been established.

The bill was violently opposed as a monopoly, but supporters were brilliantly mobilized by Boulton, and it was passed in 1775. Watt presented a memorandum to the House, excusing the monopoly on the ground that if the invention was valuable, the inventor should be recompensed for his industry and expense.

With this huge privilege, and other good fortune, progress quickened. John Wilkinson, the ironmaster, and brother-in-law of Joseph Priestley, invented a machine for boring cannon. The same machine enabled strong, accurate steam-engine cylinders to be made for the first time. Boulton and Watt ordered all their cylinders from Wilkinson for the next twenty years, and the first successful engine that they made was for Wilkinson himself to blow the blast for his iron-smelting furnaces.

The success of this engine made a big impression on industrialists, and contributed greatly to the adoption of steam engines for driving factory machinery.

Boulton and Watt now embarked on ten years of intense development. Both were at the height of their personal powers. Their chief region of activity was in Cornwall, where the cost of coal for pumping-engines was high, owing to the lack of local coal-mines. Their first Cornish order came from the Ting-tang mine, and Watt went down to supervise the erection of the engine. The Cornish mine managers, or captains, as they were called, were an independent, wild, and cunning group, according to the ancient tradition of their trade. Watt was soon deeply miserable in having to work with the terrible men, and wrote more of his imploring letters to Boulton, asking him to come at once and deal with them. There were teething difficulties with the engine, and some of the captains made coarse and wounding comments.

Watt insisted at first that the owners of the new engines should pay a quarterly premium during the period of the patent, on the saving of coal in comparison with a Newcomen engine of equal power. The Cornish captains hated this newfangled, highly scientific form of rent, which, like so many of Watt's innovations, foreshadowed developments of a century hence. Watt introduced a counter activated by the pumping-engine, for measuring the amount of water raised. He locked it in a box, in the manner of a modern power supply company, so that the engine-men could not tamper with it. The miners loved him even less for this, and ultimately he had to agree to a fixed premium depending on the size of the engine.

Fortunately, Watt acquired a young assistant of genius, his fellow Scot William Murdock, who later invented coal-gas lighting, and founded the modern gas industry. Murdock joined him in Cornwall in 1779, at the wage of one guinea a week. Besides being talented, he was frugal, and had great physical strength. When there was any misunderstanding with the miners, he rolled up his sleeves, bared his powerful muscles, and offered to fight it out. This was much more to their taste than Watt's scientificizing.

Watt could not collaborate easily with other people. He found most of them 'blockheads', and tried to do everything himself. On one occasion, Josiah Wedgwood recommended the 'oil of delegation' to him, but he had the greatest difficulty in deputing work to others. He became overwhelmed with correspondence, design, and drawings. In order to cope with them, he invented his process of copying letters. These were written with a sticky ink. A damp sheet of paper was pressed on them, and the ink came through the paper, so that it could be read. This copying-press remained the most important contribution to office equipment for a century, until the introduction of the typewriter.

Watt was so pleased with his copying-press that he copied everything, including letters to his wife. One effect of the invention was that the documentation of Watt's activities is enormous. Though he was ever moaning that his mind was declining, his power of invention disappearing, that he was losing his memory, and his health was giving way, he steadily continued to accomplish a prodigious amount of original work.

In 1782 Boulton found another gifted assistant, John Southern. Watt was doubtful of him, however, when he heard he was interested in music. He wrote to Boulton: 'If you have a notion that young Southern would be sufficiently sedate, would come to us for a reasonable sum annually and would engage for a sufficient time, I should be very glad to engage him for a drawer, provided he gives bond to give up music, otherwise I am sure he will do no good, it being the source of idleness.'

Watt and Southern invented the Indicator, an instrument that tells 'accurately what power any engine exerts'. It consisted of a small cylinder and piston. The cylinder could be connected to the cylinder of the engine, so that the pressure in it would vary as in the engine-cylinder. A pencil was attached to the piston in the indicator-cylinder, and under it a sheet of paper was moved by the stroke of the engine. The pencil drew a figure on the paper, which recorded the relations between the pressure and volume of the steam at every stage of the stroke in the working cylinder.

This great invention, which was fundamental for the scientific improvement of the steam engine, and for the development of the science of thermodynamics, was successfully concealed by the firm for twenty years. Some of their men had used one in setting up a Watt engine in Russia, and a visitor happened to see it there, and brought news of it back to England.

In 1784, Watt took out a patent for seven further improvements 'upon Fire and Steam Engines and upon Machines worked or moved by the same'. John Southern was one of the witnesses. The seventh improvement was for 'steam engines which are applied to give motion to wheel carriages for removing persons or goods, or other matters, from place to place, and in which cases the engines themselves must be portable'.

The language and penetration of this patent show Watt's powers at their highest. He was conceiving the steam engine as a prime mover, applied to an unlimited range of human aims.

His scientific and cultural knowledge grew among the distinguished members of the Lunar Society. Priestley's work on gases stimulated his imagination on the nature of water. He expressed the view that at some temperature above red heat, steam would undergo another change of state, comparable with that from water to steam. It would be decomposed into gases. He said that 'water is composed of dephlogisticated air and phlogiston deprived of part of their latent or elementary heat. . . .'

This was the first clear assertion that water is a compound, and not an element as had been believed from immemorial times. Watt was groping towards the modern ideas of the chemical composition of water, and of chemical dissociation at high temperatures. Cavendish collected the exact data on the composition of water, and Lavoisier was the first to give the complete modern conception of water as a compound of oxygen and hydrogen. From comparison of English and French measurements in the researches on the composition of water, Watt was led to propose a decimal system of weights and measures.

Watt's early engines were for operating pumps. It was not necessary for them to produce a rotary motion. But this was necessary for engines to drive mill-machinery. The use of the crank for obtaining a rotary motion from the piston seems obvious to-day, but it was not so in Watt's time. It was incompatible with the movement of the piston at a uniform speed, and it was not clear how it could get over the dead-centre. The possibility of the fly-wheel for dealing with this had not yet been fully grasped.

Watt had noted that the foot-lathe used to drive the potter's wheel contained the principle, and thought that it was not patentable. But in 1780, Pickard was granted a patent for the crank. Watt in anger immediately invented five alternatives to the crank, including the epicyclic gear. It seems that Murdock also thought of this idea independently.

Then he had to make the engine double-acting, so that the piston could exert a push, as well as a pull, as in the pumping engine. He invented a combination of rods by which this could be done. He was more proud of this parallel motion than of any of his other mechanical inventions.

He developed the ancient idea of the centrifugal governor into its modern form, for regulating the speed of the engine. Clerk Maxwell's theory of the steam-engine governor led to the modern science of cybernetics, or theory of self-governing machinery.

The steam engine was now well-launched on its way. The

Boulton and Watt firm made considerable but not extraordinary profits. As soon as they were making a useful steady income, Watt wanted to retire, and spend the rest of his days in 'ingenious indolence', pottering in his workshop, inventing anything that pleased his fancy. He was not allowed to do this, however, until the patent ran out in the year 1800. Instead, he devoted a great deal of effort to thwarting infringers of his patents. His original patent of 1769 was not well-founded in law. The members of the House of Commons had extended it because they believed it was of advantage to the new industrial manufacturers, not because they thought it good law.

Watt's legal case was weak, and he became all the more vituperative against the tiresome infringers. He particularly hated the Hornblower family, who had invented the compound engine, and he referred to them by a variety of epithets including 'horned imps of Satan'.

He opposed his own Murdock's desire to develop the steam-driven carriage, or locomotive. 'I wish', he wrote to Boulton, 'William could be brought to do as we do, to mind the business in hand', and not hunt 'shadows'. At Watt's instigation, Boulton went so far as to intercept Murdock on his way to London to seek a patent of his own for steam-carriages. Murdock allowed himself to be persuaded to return. He remained with Boulton and Watt for the rest of his career. He was presently offered a partnership in the firm, but refused this in preference for a salary of £1,000 a year without a partner's responsibilities.

Watt has been accused of meanness and jealousy towards other inventors, but it is not easy to arrive at a correct judgment on this matter. Watt had a profoundly critical genius, and he submitted everybody's ideas, including his own, to the most searching analysis. In a letter to his son in 1808, he wrote that he did not pretend to have 'an eminently inventive genius in mechanics'. His forte seemed 'to have been reflection and judgment in combining and applying things invented by myself and others'.

He was very patient in his later years in carefully explaining to the hosts of inventors who sought his opinion the main principles to which they should attend. In this way he tactfully drew their attention to fundamental principles which their ideas usually violated.

Another cause of his lack of enthusiasm was that inventions were continually swarming through his mind. He had had some notion of his own on nearly every idea, before it was put to him by another person.

As a result of his long and tremendous struggle to solve the technical problems of making his new engines, he was deeply aware of all the technical difficulties which had to be overcome before any important new idea could be realized. He strongly felt that inventors generally underestimated these difficulties, and that enthusiasm for the main idea should be moderated until it had been demonstrated that there was a fair chance that it could be carried out practically. His belief in patent monopoly was supported by his experience of the long time and great expense required to work out an idea properly. There was no other way in his own day for an inventor to gain the necessary financial backing and perhaps ten years of time for undisturbed developmental work.

These were all substantial reasons for his attitude. Coupled with them was his recurrent migraine and melancholy, which were perpetually making him feel that his mental powers were failing, and that he was about to die at any moment and leave his family destitute. These psychological problems might have been much mitigated if he had had the use of modern drugs and medical treatment for his attacks. But these did not then exist, and he just had to bear the attacks as best he could. It is not surprising that they made him querulous.

His profound insight into the nature of engineering development was more important than any other influence in forming his attitude towards the ideas of other inventors.

As the end of the original patent approached, Watt prepared for retirement. He bought a small estate on the banks of the River Wye in Radnorshire, and used to go there for the summer months.

In spite of his migraine, he outlived nearly all of his friends. Wedgwood died in 1795, Black in 1799, Darwin in 1802, Priestley in 1803, Robison in 1805, and Boulton in 1809.

He spent more and more time in his little workshop in Heathfield House, the mansion that he had built for his family in 1790 on Handsworth Heath. The workshop was in a garret over the kitchen, and next to his bedroom. He had a wonderful collection of tools and simple cooking utensils, so that he could stay there when he wished, without upsetting his wife's arrangements for the regular meals.

In his last years he amused himself with the development of a machine for copying sculptures. It appealed to his æsthetic as well as his mechanical sense, and he liked experimenting with it because, as he wrote, it enabled him to use his hands without thinking.

He extended his garden at Heathfield to about forty acres; he laid out flower and vegetable gardens, and built green-houses. He planted trees around it, so that his home became a quiet haven surrounded by beautiful greenery.

After Watt's death in 1819, Heathfield House was kept as a museum by his son, but ultimately it had to be pulled down. His little workshop, with its historic collection, has been re-erected in the Science Museum in London, where, together with many of Watt's models, it may still be seen.

James Watt's second wife was a very capable but somewhat stern housekeeper. She ordered the servants to turn out the light and rake out the fire in her husband's study at a definite hour, whether he was there or not. With his delicate health, Watt needed about eleven hours' sleep, and by these means she ensured that he went to bed in good time. According to Mary Anne Galton, Mrs. Watt had two little pug dogs which were taught by her 'never to cross the unsullied flags of the hall without wiping their feet on the mats'. It was said that she used to complain that she had less success in preventing her husband from using snuff, and persuading him to wash his hands after leaving his workshop, before entering her drawing-room.

Watt's attitude to his second family seems to have been the reverse of that to his first. His second marriage arose from his need of a manager for his household rather than from sentiment. Nevertheless, he was very fond of the children of his second marriage, Jessy and Gregory, who died young, and he left many expressions of affection for them. He showed few signs of such warm feeling for James Watt junior, the son of his first wife to whom he was profoundly attached.

When James Watt junior was a youth he ran into small debts, and existing letters show he was afraid to ask his father for aid. He wrote to Boulton senior instead, who, as usual, solved the problem practically and tactfully. The portrait of James Watt junior depicts him as a very handsome young man, of high intelligence and humour.

As James Watt junior and Matthew Boulton junior took over the firm from their fathers, its character changed. Up to 1795, the firm had been mainly consulting engineers. They supplied plans for engines and supervised their erection, but made only a few of the more complicated parts. Their income came mainly from royalties on their patents, and the manufacturing side was carried on at a loss. After the construction of the Soho Foundry in 1795 for making complete engines, including the castings, more attention was paid to the manufacturing side.

When royalties ceased in 1800 with the cessation of the patent, it became absolutely necessary to make the manufacturing efficient and profitable. The fathers had started as originators and erectors, whereas the sons were primarily organizers and manufacturers.

The young men did a very remarkable job. They invented scientific management. Professor J. G. Smith has said that there is 'nothing in the details of the most progressive factory practice of today that the two sons had not anticipated. Neither Taylor, Ford, nor other modern experts devised anything in the way of plan that cannot be discovered at Soho before 1805'. In fact, the Soho system of costing was superior to that employed in many very successful concerns of the present time. The organization of management of this earliest engineering factory was not excelled even by the skill of its new specially trained craftsmen.

The sons were intensely preoccupied with methods of time-study of individual operations, in order to find the best incentives for payment by results. They accumulated a great deal of data, and introduced very elaborate and carefully-thought-out systems of payment. They introduced a comprehensive system of social insurance for the staff.

Watt had sent his son abroad for education, Boulton sent his to Trinity College, Cambridge. The young men had been bred to organize and rule.

The difference between father and son was illustrated in the case of the Watts by the magnitudes of their fortunes. When Watt died in 1819, he left £60,000. When his son died in 1848, he left £160,000. Watt senior was the innovator of genius, not without business sense, whereas his son was primarily an organizer and business man.

Though Watt was continually lamenting during his retirement the decline of his powers, they endured very remarkably. In 1811, when he was seventy-five, he was consulted on the laying of a water-pipe on the bottom of the river Clyde, and invented one made of sections with ball-and-socket joints, so that it would be flexible and lie on the uneven bottom without excessive strains. It was a complete success. In 1814, at the age of seventy-eight he wrote in a letter to Brewster a most exact and finely expressed account of his contribution to the invention of the steam engine.

His genius was recognized almost from the beginning of his career, and he received many marks of distinction. He was elected a fellow of the Royal Society in 1785. In 1806 Glasgow University conferred on him its Doctorate of Laws. He was appointed a corresponding member of the French Academy of Sciences in 1808, and in 1814 was elected one of its eight foreign associates. The bestowal of this great honour on an engineer was unique.

He was offered a baronetcy, but refused it. His habits were simple. He liked his pipe of tobacco, or a pinch of snuff, and he was fond of all kinds of literature, serious and light, besides scientific.

He requested that he should be buried 'in the most private manner without show or parade'. He died peacefully in 1819, and was interred beside Boulton in Handsworth Parish Church.

A statue of him was erected in Westminster Abbey, by public subscription, in 1824.

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GEORGE STEPHENSON

1781–1848

George Stephenson, the 'father of the railways', was born at Wylam, a mining-village eight miles west of Newcastle, on 9 June 1781. His father, Robert Stephenson, was the fireman of a local colliery engine, a small, slight, lively man, interested in birds, and telling stories to the children sitting around the engine fire. He worked twelve hours a day, and was paid twelve shillings a week. His name was pronounced 'Stepheson', as it still is in the villages of the north-east coast.

Robert Stephenson was too poor to be able to provide his children with shoes, or send them to school. His second son George was sent out to watch the cows when he was eight, at a wage of two pence a day. Elder children were expected to keep the younger from straying on to the wooden railway which ran in front of the door of George's home. This was used for carrying coal from the colliery down to the river Tyne, in wagons hauled by horses. George spent the hours beside the cows and the railway modelling pumping engines out of clay, making their pipes out of hemlock stalks.

He was presently promoted to be a farm labourer, hoeing turnips at four pence a day, and then he rose to colliery work, where he began by picking rubbish out of coal. For this he was paid six pence a day.

In this arduous childhood, like many colliery boys, he went for long walks in the country, bird-nesting. At home, he kept rabbits, and a tamed blackbird which used to roost on the foot of his bed.

At the age of fourteen, he became an assistant-fireman at seven shillings a week. In the following year, he was appointed joint fireman at the Mid Mill Winnin pit.

Unlike his father, he was growing into a big, raw-boned muscular youth, fond of feats of weight-lifting and jumping. At this time, he appeared to be nothing more than a strong, sober, hard-working youth. One of his workmates with whom he used to have sporting competitions was Robert Hawthorn, whose sons founded the famous Newcastle engineering firm of that name.

When George was seventeen, he was made engine-man at a new pit at Water-row, being put over his father, who was taken on as fireman. The engine was built by Hawthorn, who had become the Duke of Northumberland's colliery-engine builder.

George was now receiving a man's full wage. Like his father, he was working twelve hours a day for twelve shillings a week.

The Duke of Northumberland was drawing about £50,000 a year in rents from his estates, mainly in coal royalties. His wife's equipages often excelled those of the Queen. Meanwhile, his workman George Stephenson, now wearing shoes and stockings, began, at the age of eighteen to learn to read. His curiosity was aroused by stories that those of his mates who could read, used to spell out from the newspapers in the light of the engine fire. He heard of the exploits of Napoleon, and that the Egyptians hatched eggs by incubation. The latter information appealed to his interest in birds, and he tried to hatch a mixture of many kinds of eggs. His experiment was unsuccessful, though he found that the chickens were well-developed within the shells.

He took reading and spelling lessons on three nights a week, at a fee of three pence per week. By nineteen he was able to write his own name. Then he paid four pence a week for instruction in arithmetic. He did his homework sums by the engine fire, while his dog brought his lunch from home.

He aspired to the more responsible job of brakesman, controlling the lifting up and down in the pit-shaft, but he was prevented at first from getting the necessary experience by William Locke, whose son subsequently became a celebrated engineer. Locke thought him too young and clumsy. George arranged that he should be acting as brakesman when the boss came round, so that it could be seen that he was competent. He was duly appointed brakesman at the Dolly Pit.

He was now receiving about 35*s.* to 40*s.* a fortnight. In 1801, however, wheat was 118*s.* a quarter, more than twice as much as when he was born. This was owing to the Napoleonic wars. Though at the top of his trade, he was still not earning enough to live on, and increased his income by cobbling and clock-repairing in his spare time. He repaired the shoes of his sweetheart Fanny Henderson, and carried them around in his pocket, whipping them out from time to time, boasting of his handiwork.

George used to take his engine down at the week-ends. He kept it clean and in perfect condition, and mastered it completely. He spent a lot of time, for many years, trying to make a perpetual motion machine.

He married Fanny Henderson in 1802. She had been a servant on a neighbouring farm. She was attractive, charming, sensible, and of the sweetest disposition. Their son Robert was born in 1803. In the following year George was appointed brakesman at West Moor Colliery, Killingworth.

Then he had the great misfortune to lose Fanny, who died after they had been married for only about two years. George Stephenson was deeply attached to her, and cherished her memory. It was long before he fully recovered from this calamity, and he did not marry again for fifteen years.

He was invited to be temporary superintendent of a Boulton and Watt engine at Montrose in Scotland. After lodging his infant son with a neighbour, he set off to Scotland on foot. At Montrose he proposed alterations in the Boulton and Watt engine, which were not approved by the owners, so he returned to Killingworth. On arriving at his home, he learned the dreadful news that his father had been blinded. He had been inside his engine making some adjustments, when a mate suddenly turned on the steam, which blew straight into his eyes. In those days there was no compensation or accident insurance. George had to support his father, and discharge the debts he had incurred through being incapacitated. He paid off the debts out of £28 that he had saved during his Montrose job. His father recovered his gay spirit, even after this terrible accident.

This was not the last of George's family accidents. Years later, his younger brother John was killed in the Stephenson locomotive works in Newcastle. The dangers in the new industries were great, and the accident-rate was high.

George resumed his work as brakesman at Killingworth. About 1807 he was much depressed. The distress in the country was extreme. One in seven of the working population was unemployed, and incomes of over £50 a year were subject to a tax of 10 per cent. Young men were liable to be pressed into the armed forces. George Stephenson spent his savings in buying a substitute to serve for him in the militia. He very nearly accompanied his sister and her husband in emigration to the United States, not going only because he could not raise the fare. As he had not served an apprenticeship, he had nearly despaired of ever becoming an engineer.

However, by using every opportunity of showing his competence to his employers, he succeeded in rising still further, but even this occurred owing to a vacancy caused by yet another fatal accident. The engine-wright at Killingworth, Old Cree, was killed in 1812, and George was appointed to succeed him, at £100 a year. For this salary, he was to keep in proper order the engines of a colliery that contained nearly 160 miles of galleries.

While in this job, he worked out methods of using an underground steam-engine for replacing manual labour and horse-haulage, and succeeded in reducing the number of horses required in one pit from about 100 to 16. The price of feeding corn was then very high, which increased the importance of these experiments.

George and his son Robert, then about ten years old, worked together in the evenings as fellow-students of reading, writing, arithmetic, and science.

The need for a better power than horses for railway-hauling was inspiring many experiments. Blackett, the proprietor of the Wylam railway beside which Stephenson had been born, ordered steam-locomotives in 1811 from Trevithick, who had made the first steam-locomotive to haul a train successfully seven years before.

Trevithick had broken away completely from Watt's prejudice against high-pressure steam, and his engine contained the embryo of the modern locomotive. While he had most of the basic ideas, he lacked the patience for the development-work which was necessary to convert his engine into a reliable industrial machine. He did not realize that an engine could haul successfully with smooth wheels on smooth rails. Neither did Blenkinsop, who had introduced a steam-locomotive which operated by revolving a toothed wheel on a rack laid beside the railway.

For the mining men, Coulomb's experiments on friction might have belonged to another world. In those days, the division between practical men and scientists was often complete. They did not believe that the resistance of a wagon to motion was independent of the speed until Blackett and Hedley had made full-scale experiments in 1813.

Stephenson saw the experiments with the Trevithick locomotive on the Wylam railway, and he saw Blenkinsop locomotives in use. The former was roughly made by blacksmiths, the latter well-made by skilled craftsmen. But it was slow and inefficient owing to its rack-drive.

He meditated on these experiences, and brought steam-locomotives to the notice of Lord Ravensworth, the principal partner of the Killingworth colliery. Ravensworth authorized him to construct one for the colliery. He completed this in 1814. He named it 'Blutcher'. This was the local pronunciation of Blücher, the famous Prussian general and ally of Wellington at the Battle of Waterloo, after whom one of the Killingworth pits had been named. It was the first locomotive to have smooth wheels, and successfully hauled a train of eight loaded wagons weighing thirty tons up a gradient of 1 in 450, at four miles an hour.

But it was too slow to be a decisive improvement on horses. Then Stephenson thought of increasing the rate of steam-raising in the boiler by using the exhaust-steam as a blast up the chimney, and thus increasing the draught through the boiler furnace. Trevithick had conceived the same idea years before, but never published or applied it.

By 1815 Stephenson had constructed a locomotive with smooth wheels, connecting-rods, steam-blast, and direct drive from the cylinders to the wheels.

While engaged in these developments, he continued clock-repairing and other ways of earning extra money in his spare time. He spoke in his later years of how he had often got up at one or two in the morning, and worked until late at night, to carry out all his tasks.

He saved one hundred gold guineas, which he sold to Jewish hawkers for twenty-six shillings each. He lent some of the proceeds at good interest, and some he spent on sending his boy Robert to the best boys' school in Newcastle, in 1814.

Robert was then thin and delicate. He walked the ten miles to school in iron-shod boots, corduroy trousers, and a blue miners'-jacket. He carried books, rye bread and cheese in his bag. He was at first an object of ridicule to the sons of the middle-class citizens of Newcastle, and ate his dinner apart.

George took out a three-guinea subscription for Robert to become a member of the Newcastle Literary and Scientific Society. He instructed his twelve-year-old boy to comb the technical journals for information on engines and science, which might be of interest to them. In 1820 he sent Robert to Edinburgh University for six months. It was the only college where instruction in science could be obtained at a moderate expense. Robert's short sojourn cost £80, and he returned with a mathematics prize, and the friendship of George Bidder, the famous calculating boy, who later became his noted engineering colleague, specializing as an expert witness before Parliamentary committees, where his powers of almost instantaneous calculation were particularly disconcerting to the side to which he was opposed.

While Stephenson was constructing his first locomotives, he became interested in the problems of a safety lamp for miners. As colliery engine-wright he had to cope with many explosions. In one case, in 1814, he went into a burning gallery with six volunteers and walled it up. Years later, after he was famous, he gave some remarkable first-hand descriptions of coal-mine explosions to parliamentary committees. But while he was still a colliery engine-wright, he made interesting experiments on the actual behaviour of flames in the pit. He told a parliamentary committee that he had observed the speed at which the flame of the ignited fire-damp passed along the roof, and he considered that if he could produce a current through tubes in a lamp which had an equal speed, he could make a lamp which could be taken into an explosive mine atmosphere without igniting it.

Following up this idea, he devised a lamp in which the atmosphere entered through fine tubes. At about the same time, Sir Humphry Davy was asked to investigate the same problem. His assistant Michael Faraday, then quite unknown, carried out the basic research on the properties of flames in tubes under Davy's direction. Davy arrived at the same design as Stephenson, but more elegantly, and with a correct scientific explanation of its principles. But Stephenson had invented a similar lamp independently, and made the first safety lamp of this type.

A public testimonial of £2,000 was given to Davy, and a consolation prize of one hundred guineas to Stephenson. There was a sharp controversy on priority. The attitude of Davy's supporters was expressed by his biographer Paris in 1831, publishing after Stephenson had built the Liverpool and Manchester Railway, that it was scarcely credible that 'an engine-wright of Killingworth, of the name of Stephenson—a person not even possessing a knowledge of the elements of chemistry', could have made such an invention.

The first safe, though clumsy, miners' lamp had, in fact, been proposed by Alexander von Humboldt in 1796.

Stephenson's mining friends organized their own testimonial for him, which amounted to £1,000.

Thus the unschooled engine-wright, who could write only with difficulty, had by 1815 accomplished important achievements in two separate directions; in the construction of locomotives and in the invention of a safety lamp.

No less than eight years passed before Stephenson's introduction of steam locomotives at Killingworth attracted notice outside the locality. This was perhaps his greatest piece of good fortune, but it did not appear so at the time. He was able to spend eight long years gradually improving his locomotives and his railway track, 'man and wife', as he called them, until he had learned from experience all the difficulties, and had discovered how to solve them.

When he found his way to a wider arena, he arrived as a complete and experienced railway engineer, not as a genius with a mixture of brilliant and unsound ideas, which had not yet been tried out. It was this detailed knowledge, derived from long, successful experience, which gave him the foundation that subsequently enabled him to withstand the sceptical jeering onslaught of nearly the whole of the engineering and scientific world.

The first person of wide experience to recognize the abilities of Stephenson was William James, the land-agent of the Duke of Northumberland, the Archbishop of Canterbury, and other magnates. He visited Killingworth in 1821. James had long been interested in the possibility of steam-locomotive railways, and had visited Trevithick in Cornwall as early as 1803, to discuss the problem. He was interested in the possibility of a railway between Liverpool and Manchester, and many other schemes. He was an enthusiastic and unsuccessful projector, so his advocacy was double-edged. On the one side, he talked to influential people all over England of the persons and things that interested him, and on the other, he put people off by his numerous losses and failures.

While James helped to make Stephenson known, fresh opportunity came from a quarter of a very different kind. Edward Pease and his Darlington Quaker friends had acquired an interest in the rich coal reserves in the Bishop Auckland valley. He wanted a railway to make them accessible. He was a mature man of nearly fifty when he conceived this project, and he proceeded with the cautious determination of a Quaker business man. His first idea was of a horse-tram road from Witton colliery to Stockton, and this grew into the project for the Stockton and Darlington railway. After nearly ten years of patient overcoming of opposition, Parliament passed the necessary act, empowering its construction, in 1821. The public were to be free to use the railway with their own horses and carriages.

Stephenson heard of the Stockton and Darlington Act, and went to Darlington at the end of 1821 to offer his services as constructor to Pease. Being diffident, he brought with him his friend Nicholas Wood to speak for him. The experienced and wise Pease at once saw that he had before him a remarkable man. 'There was such an honest, sensible look about him, and he seemed so modest and unpretending. He spoke in the strong Northumbrian dialect of his district, and described himself as "only the engine-wright at Killingworth, that's what he was".'

Stephenson was then forty years, and Pease fifty-five years old. Pease informed Stephenson that he proposed to use horses on the new iron road, whereupon Stephenson told him that his steam locomotives at Killingworth were worth fifty horses. 'Come over to Killingworth and see what my Blutcher can do: seeing is believing, sir.' Pease said that he would.

Stephenson told Pease at their first meeting that he deduced from his physiognomy that he was not a man to be deterred by difficulties. To which Pease replied: 'I think so, too, and I may observe to thee, that if thou succeed in making this a good railway, thou may consider thy fortune as good as made.' Pease said he would recommend him as engineer for the new railway, and Stephenson informed Pease that he and Wood proposed to return to Killingworth in the same manner that they had come: 'by nip'. This consisted of a smuggled lift on the stagecoach, obtained by tipping the coachman.

Pease made careful inquiries about Stephenson through other Quakers, and hearing excellent reports from them, had him engaged as engineer. 'We wish thee', said Pease, 'to proceed in all thy levels, estimates and calculations, with that care and economy which would influence thee if the whole of the work were thy own.'

Pease duly went to Killingworth, and found his way to

Stephenson's cottage. The door was opened by his wife, who said that her husband was in the colliery. He was sent for, and arrived from the pit in his working clothes. He took Pease for runs on his locomotive, and converted him to locomotive haulage for the new railway. An amended Stockton and Darlington Act was passed in 1823, containing a clause, inserted at Stephenson's urgent request, that the locomotive engines should be used for transporting passengers as well as merchandise. This was the first parliamentary act in which the hauling of passengers by steam locomotives was sanctioned.

Stephenson's engagement as engineer to the railway was confirmed, and his salary was fixed at £300 a year. He brought his family to Darlington.

He conducted the survey of every foot of the line personally. He set off in the morning in top boots and breeches, with a piece of raw bacon and a hunk of bread in his pocket. About midday, he called at the nearest cottage, and got his bacon fried, together with eggs, and a drink of milk. He became known and liked all along the line, for he had a gay and friendly manner and played with the children, if any were about.

At the end of the day he called on Mr. Pease, to report progress. Pease's daughters were usually present, and on one of these occasions Stephenson found them learning embroidery. He at once offered to instruct them. He had learned all about it at Killingworth, 'while working the pitman's button-holes by the engine-fire at nights'.

His conversation was amusing and instructive. He illustrated his points with all sorts of odd information and experiences. He was very observant and had a strong memory. These faculties might have made him prosaic, but this was not so. He was imaginative and speculative, and would suddenly reveal familiar things in new perspectives. He particularly liked discussing new scientific theories, and he made surprising religious speculations. With his vast, homely common sense, he was independent in forming his own point of view.

He was a successful leader of men. He was entirely at home among the workmen, and was able without apparent effort to secure their most devoted labour, and to preserve good discipline. Yet he was fond of saying that he found it very much easier to engineer matter than to engineer men.

There was determined opposition to the railway from local landowners, but every obstruction was overcome by Pease's skill and persistence. His motto for the railway was 'At private risk for public service' (*Periculum privatum utilitas publica*). Mr. Lambton, the future Earl of Durham, had had a clause put into the Stockton and Darlington Railway Act, that the charge for hauling coal to Stockton was to be not more than a halfpenny per ton-mile, whereas the owners were to be allowed to charge fourpence per ton-mile for sales of coal at inland places beside the railway. He did not believe that the coal could be hauled economically at that price to the port of Stockton, and hence that his own exports of coal from Sunderland would thereby be protected. Pease had not in fact foreseen any considerable transport of coal to Stockton, but to his surprise it grew at a great rate. He and his partners decided to build a dock beside a farmhouse in a mud-flat five miles down the river, specially to handle the trade. This was the origin of the port and town of Middlesbrough. Within ten years the export had grown to more than half a million tons a year. The halfpenny rate for these huge quantities proved ultimately to be the largest source of profit.

To return, however, to the opening of the railway in 1825. A train of loaded wagons was drawn up the Brusselton Incline, which was too steep for the existing locomotives, by a fixed engine, and lowered down on the other side. A passenger coach containing the Directors, twenty-one wagons with temporary seats for passengers, and six loaded coal wagons were joined on to them, making a train of thirty-eight vehicles. One of Stephenson's locomotives, driven by himself, was hitched on to the train, which weighed altogether about ninety tons and contained 450 passengers, and the journey to Darlington began. Thousands of people had assembled to watch the sight, and many expected that the engine would blow up. The distance of 8¾ miles was covered in 65 minutes, and in places the speed exceeded 12 miles an hour. At Darlington the six coal wagons were detached, and the engine took in more water. To the strains of a band the train set off for Stockton, covering the 12 miles, with stops, in 3 hours 7 minutes. By the time that it arrived, 600 passengers were hanging on to the wagons, and the Stockton crowd looked at the sight with wonder.

As with the coal export trade, the growth of passenger traffic also had not been foreseen. Pease had ignored possible passenger traffic receipts in his forecasts of the economics of the railway. Stephenson urged that a regular passenger coach, hauled by a horse, should be put on as an 'expurriment', so it was called the 'Experiment', and was decorated with the company's arms and motto.

The horse-drawn coach ran at about 10 miles an hour. It was found that the possibility of quicker travel increased the number of travellers. Locomotives were not used for passenger traffic, but for hauling the coal trains, and even a large part of the coal traffic was still hauled by horses, as the lines sloped down to the sea, so that great tractive effort was not generally required.

It was typical of Stephenson that he did not press fanatically for locomotives only, but continued to use stationary engines and cables on heavy inclines and horses for lighter traffic.

In his discussions with Pease, several of the main features of the railway design for the future were decided. The gauge of 4 feet 8½ inches was adopted from that of the colliery train roads, and was derived from the common cart. It was decided to use wrought-iron instead of cast-iron rails, as far as possible, in spite of their extra expense; and it was decided to use steam locomotives.

Stephenson had suggested to Pease that a factory for making locomotives should be established in Newcastle. Formerly, his locomotives had been made by the mechanics found about his collieries. The engines were rough-and-ready contrivances, and would evidently be much better if made by mechanics specializing in the work in a factory fitted for the purpose. He told Pease that he could contribute the thousand pounds that he had received as a testimonial for the miners' safety-lamp as part of the capital. Pease and his friend Richardson added five hundred pounds each, and with the total of two thousand pounds, the factory was founded in 1823.

The construction of three locomotives for the Stockton and Darlington Railway was put in hand, and the stationary engine for the Brusselton Incline. This was designed by Robert Stephenson.

In the course of a few years, many skilled locomotive engineers were trained. Men came there to learn from many parts of the world, and returned to their native lands trained in the ideas and skill of Stephenson.

Robert Stephenson was absorbed in the intense constructive labours with his father, but again his health showed signs of breaking down, with symptoms of consumption. He pined to escape from the rigours of Newcastle. In 1824 he was offered the post of engineer to the Colombian Mining Association, an enterprise inspired by Alexander von Humboldt's reports on South America. Though his father was loath to lose him, he urged him to go. He left for Colombia in 1824. Three years later, with the prospect of the Liverpool and Manchester railway on his hands, Stephenson sent for him to return. The warm climate had been good for Robert's health, and he came back cured of bronchial trouble. While waiting in a ramshackle hotel at Cartagena for a ship to bring him home, he saw, one day, two men who looked like Englishmen. He went up to them, and found that one, a tall gaunt man, was Richard Trevithick. He was penniless, and Robert lent him £50 to buy a passage back to England. They had many conversations about railways and the possibilities of steam locomotives.

Robert rejoined the Newcastle locomotive works in 1827, to collaborate in the design of the famous *Rocket* for the forthcoming Liverpool and Manchester railway, and a further quarter of a century of achievement. Among many of the great constructions which he carried out were the Menai Bridge, and the High Level Bridge at Newcastle. When he died in 1859, he left a large fortune. Trevithick, who had made the first steam locomotive to haul a train, and introduced the high-pressure steam-engine, was buried in a pauper's unknown grave in 1833. He had brilliant inspiration and foresight, and a splendid sense of design, but his wild and passionate nature unfitted him for developmental work. Complete invention consists of much more than the idea. It includes the realization of the idea in a machine, and its establishment as a standard industrial product. It was in these parts of invention that George Stephenson was so outstanding, and in which he received great help from his son.

While the Stockton and Darlington Railway was being constructed the project of a railway between Liverpool and Manchester was being canvassed, especially by William James, who had business as a land-agent in the neighbourhood of Liverpool.

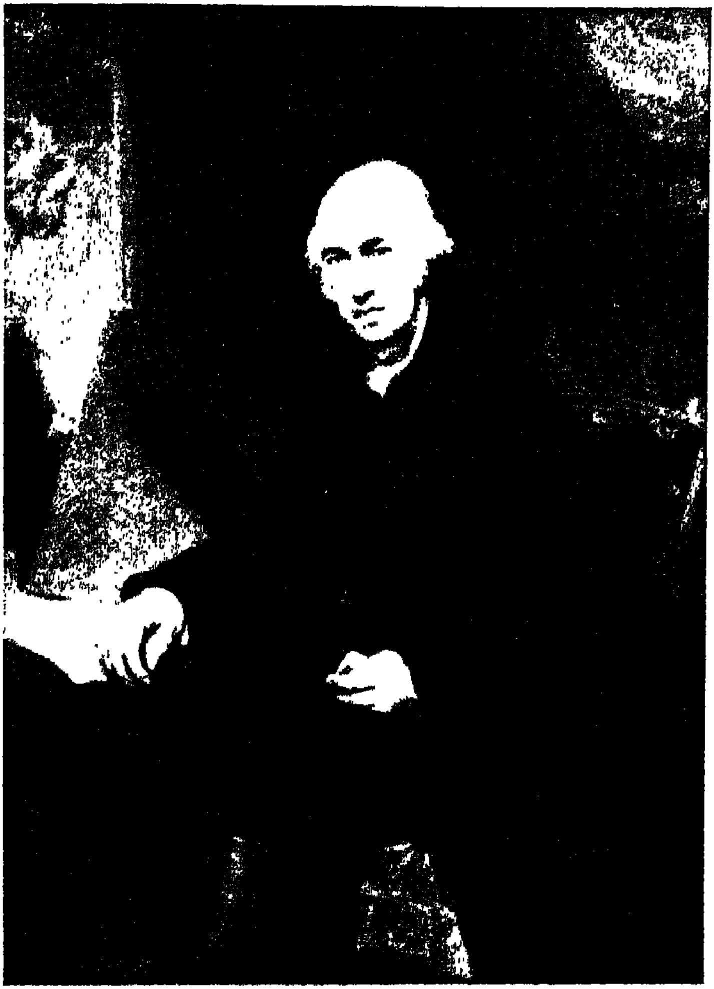
The growth of the Lancashire cotton industry had immensely increased the trade between Liverpool and Manchester. Tens of thousands of tons of raw cotton were brought to Liverpool from America, and then sent on to Manchester for distribution in the various regions of the industry. A large part of the cotton returned to Liverpool in the form of manufactured goods for export. Together with this expansion in the cotton trade itself, the related trades expanded in proportion.

The main artery of all this trade was the Duke of Bridgewater's Canal. It enjoyed a monopoly, and had paid a dividend of 50 per cent, about £100,000, every year for fifty years. Brindley had been paid a workman's wage for building it. Besides being expensive, it was also very inefficient. The transport of raw cotton from Liverpool to Manchester often took far longer than across the Atlantic Ocean from America to Liverpool. When the canal was frozen transport stopped altogether, and widespread unemployment was caused, besides loss of trade.

The Liverpool merchants and Manchester manufacturers were being driven to find a solution. James was in touch with them, and inspired preliminary surveys of the route. The Earl of Derby, the Bridgewater Trustees and other bodies raised every difficulty, and the local inhabitants were instigated to attack the surveyors when they trespassed on hostile owners' land. The surveyors replied by forming bodyguards of bruisers. The survey was naturally very imperfect, and nothing came of it immediately.

Three years later, a trade boom made the situation still more unbearable. One hundred and fifty principal merchants of Liverpool announced that 'a new line of conveyance has become absolutely necessary to conduct the increasing trade of the country with speed, certainty, and economy'.

A committee was formed to investigate what might be done. It contained several Quakers, and they sent a deputation to Darlington to see what their friend Pease, and



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From the portrait by Sir Thomas Lawrence

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GEORGE STEPHENSON

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Stephenson, were doing. They found them in the midst of the construction of the Stockton and Darlington Railway, and Stephenson took them to Killingworth to see his locomotives. The deputation reported in favour of a double-track railway between Liverpool and Manchester.

A prospectus for the project was issued in 1824. It was a cautious and very business-like document, signed by Gladstone, Ewart, Cropper, Potter, Sharpe, and other well-known Lancashire business men. It was estimated that the railway would reduce the time of transit between the two cities from 36 to about 4 hours. Its value was rated almost entirely for the conveyance of goods, and no estimate of the possible size of passenger traffic was offered.

The capital required was estimated at £400,000, and four thousand £100 shares were issued, and no one was permitted to hold more than ten. Consequently, a wide range of the leading Lancashire merchants and manufacturers were involved in it. The Liverpool and Manchester Railway Company was very definitely an instrument of the Lancashire industrialists, carefully designed for their own service, and not a speculative venture.

The Company sent two more deputations to Killingworth to help them to come to a decision on the locomotive and engineering side of their project.

William James had by this time become bankrupt, and had had to flee the country. He gave the results of his survey to the Company, and recommended Stephenson as their engineer. Stephenson was asked to make a new survey. Like James, he was attacked for trespassing, but showed redoubtable command of manœuvre, arranging that the landlords' keepers and farmers were outnumbered by his 'surveyors'. When asked by the Parliamentary Committee on the Company's Bill why he had trespassed on Lord Derby's land, he replied that he had gone there because he had received the orders of the Company to make the survey there. The Duke of Bridgewater's retainers threatened to duck him in a pond, so, he told the committee, a great deal of the survey had to be done by stealth, while the occupiers were at dinner, or before they had got up in the morning. Strawberry beds and cornfields were trampled down. The lands of obstreperous vicars were surveyed while they were delivering their sermons.

Stephenson's survey was rough, for he was not a professional surveyor, and the interferences prevented him from obtaining many important measurements. With these weak data, he had to appear before a House of Commons committee in 1825, to give evidence in favour of the railway.

The opposition had engaged a galaxy of the greatest lawyers to present their case, and had retained nearly all of the leading engineers in the country as expert witnesses. Stephenson could not find one engineer who knew anything about railways to give evidence in his support. The counsel for the railway were terrified by his bold views. He said that he confidently expected that his locomotive would run at twenty miles an hour, and 'Brougham frankly told him that if he did not moderate his views he would inevitably damn the whole thing, and be himself regarded as a maniac fit for Bedlam'.

When Stephenson went before the Parliamentary Committee, which was the first time he had had such an experience, he was cross-examined by ten lawyers. They made jokes about his Northumbrian accent, and asked whether he was a foreigner. When he said that his locomotive could run at twelve miles an hour, members hinted that he must be mad, and suffering from delusions. He was asked how smooth wheels could haul without slipping, and whether the train would jump curves at speed. Attempts were made to trip him over elementary theoretical mechanics. He was asked whether it would not be very awkward to have to stop an engine running at twelve miles an hour, if a cow wandered on to the line. 'Yes,' said Stephenson, 'verry awkward indeed—for the coo.'

The shortcomings in his survey were mercilessly exposed, and he was examined at length on the problem of crossing the great bog Chat Moss, which was four miles wide. He had not ascertained that it was thirty-seven feet deep. Stephenson appeared quite confident that he could lay the track across, though all other engineers believed that it would be necessary to dig out the bog and lay a solid embankment on its bottom, which would be an enormous work. A leading civil engineer was called to give an estimate of the cost, which he put at £270,000. Counsel described Stephenson as an unprofessional person not in his senses, a grossly ignorant so-called engineer who proposed 'an impossible railway' through Chat Moss.

After two months of struggle, the main clause to empower the building of the railway was defeated, and the bill was withdrawn. Thomas Creevey, who was a member of the Committee, rejoiced that 'this infernal nuisance—the locomotive Monster, carrying eighty tons of goods, and navigated by a tail of smoke... this devil of a railway is strangled at last'.

But the need for the railway was so pressing that the member of Parliament for Liverpool William Huskisson, the most influential statesman-economist in the period between Pitt and Peel, recommended the company to try again. This time, the Rennies, the leading civil engineers, familiar with parliamentary procedure, were engaged to make a new survey. Special care was taken to avoid the landowners' game preserves, and other sensitive places. The Rennies' estimate was considerably more than Stephenson's, but by this time, lobbying had become much more effective, and the bill, incorporating the estimate, was passed. The cost of obtaining the act was £27,000.

George Rennie was now asked to be engineer of the railway, but he said he could only give part of his time to it. The company thereupon appointed Stephenson as engineer at a salary of £1,000 a year. Stephenson immediately started on the 'impossible' part of the work, the crossing of Chat Moss. He cut ditches beside the line of the track, so that the moss was gradually dried out. Hurdles covered with heather were laid on top of the dried moss, and then soil or ballast on top of the hurdles, until the required level was obtained.

In some reaches, the amount of ballast poured in appeared to be interminable. Ultimately, everyone except Stephenson lost their nerve, and came to the conclusion that the civil engineers' report to the Parliamentary Committee was correct—the construction was impossible. A meeting of the directors was called to consider abandoning it. However, they had spent so much already that, as Stephenson put it, they felt compelled to go forward, against their will.

Stephenson thereupon stepped up the rate of pouring ballast into the bog. Soon the surface became firm, and six months later he had a locomotive running over it.

Stephenson's idea was to make the embankment float in the bog. He argued that if a ship could float then one ought to be able to make an embankment that would float. He was appealing to the principle of isostasy, by which the Alps and the Himalayas float in the surface of the earth.

The cost of his track across Chat Moss proved to be only £28,000, compared with the £270,000 estimate of the orthodox civil engineers. This was the most spectacular example of Stephenson's genius. He had a profound insight into scientific principles, which he had not learned from 'buicks', (he was always advising others to read, but fell asleep over books himself) but had worked out from first principles for himself. His invention of the safety-lamp was another example. In 1845, when he was staying with Sir Robert Peel, he was engaged in conversation with the eminent botanist, Buckland. 'Now, Buckland,' said Stephenson, 'what is the power that is driving that train?' 'Well,' said Buckland, 'I suppose it is one of your big engines.' 'But what drives the engine?' 'Oh, very likely a canny Newcastle driver.' 'What do you say to the light of the sun?' 'How can that be?' asked the doctor. 'It is nothing else,' said the engineer: 'it is light bottled up in the earth for tens of thousands of years—light, absorbed by plants and vegetables. . . .'

Stephenson directed the building of sixty-three bridges, including a viaduct seventy feet high, with nine arches, over the Sankey Canal, and a skew bridge at Rainhill. A deep cutting two miles long through solid sandstone rock was made for the approach to Liverpool, and a tunnel 2,240 yards long into the city. Three million cubic yards of earth were shifted for cuttings and embankments.

The organizing of the labour-force to carry out these great works was a new problem. No large contractors were then in existence. Stephenson took over the much smaller numbers of men who had dug the canals, or navigating channels. and were therefore called 'navigators', or 'navvies'. Their numbers were greatly increased, and in the course of a few years they grew into an army of nearly 200,000 men. Nothing like them had been seen since the days of the Pyramids, and the Great Wall of China. They worked in innumerable small gangs, with spades and wheel-barrows and horse-drawn carts. Steam-shovels and bulldozers had not yet been invented. They lived in mud-huts, or in gangs of twenty-five in wooden sheds, beside the line. They were paid about twice the usual rate of wages, but at long intervals. When they received a pay-packet, it was relatively big, and they descended on neighbouring villages, and drank and roared them dry. They consumed large quantities of beef and beer, to sustain their brawn. Many of them had fancy names, such as Gipsy Joe and Fighting Jack. Edwin Chadwick, the famous founder of modern sanitation, reported in 1845 that they had their own distinctive laws and customs. Couples were married by the ceremony of jumping over a broomstick, and then and there put to bed, in a beer-hall full of men.

The navvies became highly expert workers in cuttings and tunnels. The jobs with the highest prestige were those which were the most dangerous and difficult.

Stephenson showed a remarkable power of leading this heterogeneous and wild army. When the tunnel under Liverpool was being bored, beds of wet sand and loose rock were encountered, and on one occasion, in his absence, there was a bad fall. When he returned, he found that the navvies had withdrawn, and refused to re-enter the works. He at once called for volunteers, and led a gang in himself to repair the roof and make it safe.

His long experience in the Northumberland collieries of falls and explosions and constant danger and accidents enabled him to deal with all the menaces of the new railway engineering without a qualm, and with the utmost skill and composure. The construction of the railways would have been impossible without a mastery of mining-technique.

In spite of the unique character of the work, the directors were restive over its rate of progress, as they were losing interest on their heavy investment. Stephenson organized double shifts of navvies, the night shift working by torchlight. It was at this time that he sent for Robert to return from South America, and assist him.

Though Stephenson was the engineer to the railway, the form of haulage had still not been finally decided. In view of the conflicting opinions, the directors decided to offer a prize of £500 for the best locomotive engine, which would regularly haul a train of twenty tons at ten miles an hour, and with a boiler pressure of not more than 50 lb. to the square inch. A number of other specifications were laid down, including the price, which was not to exceed £550.

Under Stephenson's direction, his son Robert superintended the design and construction of their entry, the *Rocket*. It was evident that if the locomotive was to achieve sufficient speed, the boiler would have to produce more steam than earlier models. This was achieved by adopting a suggestion of Henry Booth, the secretary of the company, that the flue should be replaced by many flue-tubes, greatly increasing the area, and hence the heating surface, for the amount of hot gases passing from the furnace to the chimney.

The Stephensons succeeded in producing a light, wel-balanced, cleanly-designed engine, which proved to be the embryo of its successors for the next hundred years.

A piece of level track, about two miles long, near Rainhill, was chosen for the half-dozen competing engines to show their paces. They were to make twenty runs, amounting to about seventy miles, during the day, and the average speed was to be not less than ten miles an hour.

At least ten thousand spectators assembled to watch the trials. One of them was J. P. Joule, then a twelve-year-old boy, who later discovered the conservation of energy. The *Rocket* was ready first, and completed all its runs at an average speed of fifteen miles an hour, with a maximum speed of twenty-nine miles an hour. 'It seemed indeed to fly, presenting one of the most sublime spectacles of mechanical ingenuity and human daring the world ever beheld. It actually made one giddy to look at it,' one eyewitness wrote. It easily won the prize, and demonstrated the practicability of steam locomotion for railways. The shares of the company immediately rose in value by ten per cent. The *Scotsman* reported that the Rainhill experiments had given a greater impulse to civilization than any innovation since printing. 'It is no exaggeration to say, that the introduction of steam-carriages on railways places us on the verge of a new era—of a social revolution of which imagination cannot picture the ultimate effects.'

Fanny Kemble, then a young woman, was driven over the line on the footplate of the *Rocket* by George Stephenson himself, shortly before it was opened. She described her experience in one of her famous letters. They were first of all introduced to the engine: 'She (for they make these curious little fire-horses all mares) consisted of a boiler, . . . and a barrel containing enough water to prevent her being thirsty for fifteen miles. . . . She goes on two wheels which are her feet, and are moved by bright steel legs called pistons; these are propelled by steam. . . . The reins, bit, and bridle of this wonderful beast is a small steel handle. . . . You can't imagine how strange it seemed to be journeying thus, without any visible cause of progress other than the magical machine, with its flying white breath and rhythmical, unvarying pace, between rocky walls . . . bridges were thrown from side to side across the top . . . and the people looking down . . . seemed like pygmies standing in the sky. . . .'

The young actress now recorded 'a word or two' about George Stephenson, 'the master of all these marvels, with whom I am most horribly in love. He is a man of from fifty to fifty-five years of age; his face is fine, though careworn, and bears an expression of deep thoughtfulness; his mode of explaining his ideas is peculiar and very original, striking, and forcible; and although his accent indicates strongly his north-country birth, his language has not the slightest touch of vulgarity or coarseness. He has certainly turned my head'.

The railway was opened officially on 15 September 1830. Eight trains drawn by Stephenson locomotives set off from Liverpool before cheering multitudes, marshalled by hundreds of policemen and soldiers. The Duke of Wellington, then prime minister, Sir Robert Peel and Mr. William Huskisson were among the eminent personages in the carriages of the ceremonial trains. Seventeen miles from Liverpool the trains stopped for the engines to water, and the *Northumbrian* locomotive, with the Duke's carriage attached, was drawn up on one line, so that the other trains could steam by, as in a march-past. While the trains were being marshalled, Huskisson alighted from his carriage, to take a turn to and fro. The Duke, whose relations with Huskisson had been cool, waved to him in friendly recognition, and Huskisson crossed the line to shake him by the hand. He inadvertently got in front of the approaching *Rocket*, and was run over. He was terribly wounded, and was driven at a speed of thirty-six miles an hour to Eccles, for medical aid, but he died within a few hours. He had done more than any other statesman to secure the construction of the railway, and was killed on its opening day.

In spite of this tragic accident, the railway was an immediate success, especially for passenger traffic. This had been estimated at 500 a day, but the figure proved from the beginning to be about 1,200 a day. The train took about one and a half hours, compared with four hours by coach. The annual profit proved to be about thirty per cent higher than the estimate.

The owners of land near the railway, who had so violently opposed its construction, found that the value of their land was rising rapidly.

The Liverpool and Manchester was the first complete railway according to the modern conception, and its success led to the establishment of the public railways of all the world.

George Stephenson and his son proceeded to works much greater in size than the Liverpool and Manchester, but no future railway, not even one which went right round the earth, could have had as much significance as this.

They were appointed engineers to the London and Birmingham Railway. The landlords' opposition was now mercenary rather than violent. £750,000 was paid for land valued at £250,000, and the expenses of securing the Act of Parliament for the line were £72,868. The inhabitants of Northampton were instigated to demand that the line should not come near their town. In order to meet their objection, it became necessary to drive an immense tunnel, 2,400 yards long, through a neighbouring hill, at Kilsby. Soon after the excavation began, the tunnellers found themselves menaced by floods of water from a huge hidden quicksand, which had been missed by the preliminary borings made by the surveyors. The contractor for the tunnel was terrified by the dangers and losses which threatened him, and he actually died of shock.

The general opinion of all engineers consulted on the disaster was that further progress was impossible, and the tunnel would have to be abandoned. After these reports, Robert Stephenson undertook the responsibility of completing the tunnel himself. He installed a battery of thirteen of the largest steam pumping-engines to get the water down, and gangs of bricklayers laid bricks in cement to form the tunnel arch. Presently, water burst in with such violence that the men had to scramble on to a raft, and were in danger of being crushed against the roof of the tunnel. One of the engineers jumped into the water, and swam to the bottom of the vertical ventilation shaft, towing the raft by a piece of rope held between his teeth. They got there and were then hauled up to the surface, on the top of the hill. It seemed that the tunnel was now finally drowned out, but Robert Stephenson kept the engines going, and presently the water began to fall. The tunnel was completed in eighteen months, 36,000,000 bricks having been laid. Its cost had risen from the original estimate of £99,000 to £350,000. Yet with this, and other great unforeseen expenses, the line, which was opened in 1838, immediately paid large dividends.

The working conditions of these engineering pioneers were of a heroic character. One of Robert Stephenson's young draughtsmen, John Brunton, has left a description of how the drawings were got out for the London and Birmingham Railway. Owing to the lack of large contractors and the necessity for employing many small firms, a very large number of drawings had to be made in order to fit together all the various contributions, and enable the many separate firms to function as a whole.

The Eyre Arms Tavern near St. John's Wood, which was empty at the time, was rented by Robert Stephenson. The old ballroom was turned into a drawing-office. Twenty draughtsmen drew continuously on day shift, and were followed by another twenty on night shift. All drawings for a certain section had to be ready within a fortnight. Brunton got to bed for only one night during that fortnight. When all the drawings were ready, George Stephenson himself appeared, and said: 'Halloo, Brunton, I can find nobody to take these plans down to Birmingham to-night, so you must take them.' Brunton remonstrated about the amount of work he had just completed during the last fortnight, but he went. He could get nothing better than an outside place on the coach. He fell asleep immediately, and was shaken awake at Birmingham. After delivering the drawings, he went to stay with a relative at Coventry. He was put to bed, and remained unconscious for three weeks.

Robert Stephenson, in constructing the line between London and Birmingham, walked over the whole distance, surveying and supervising, twenty times—more than two thousand miles.

George Stephenson was in the habit of commandeering any available young engineer as his local secretary on visits to works in progress. When he was constructing the Manchester and Leeds Railway, he offered a job on it to Brunton. One day he came to inspect the works, and Brunton had to act as secretary. Stephenson told him to get a horse carriage to drive him from Wakefield to Manchester, in order to catch the express for Liverpool. The carriage was quickly secured, and the drive started. When they reached Littleborough, a man in a leather apron came out to open the toll gate. 'Halloo,' said Stephenson, 'ye are a shoemaker, are ye?' 'Aye,' said the man. 'Do ye ken hoo to mak cobblers' wax?' 'No, sir,' says the man, 'I generally buys it.' 'What? you a shoemaker and dinna ken hoo to mak cobblers' wax. Open the door, open the door!' Brunton remonstrated that they had no time to spare and would miss the train at Manchester if they got out. But Stephenson replied: 'Mon, here's a shoemaker doesna ken hoo to mak cobblers' wax.'

Stephenson got out, and showed him. They missed the train, but Brunton heard a long and most interesting discourse on self-reliance, and the advantage of making oneself the master of every detail of one's business.

George Stephenson accomplished enormous achievements in the conception and construction of railways, but their promotion and financing was outside his range of ideas and abilities. In these spheres, he was dependent on others. The business of the Stockton and Darlington, and the Liverpool and Manchester, railways, was conducted in the main by very able Quakers, who worked on cautious and solid principles.

The unexpectedly great financial success of these first railways immediately attracted others with different principles, whose main desire was to make money as quickly as possible, and who regarded the railways as a rich new vein for speculative investment. By the 1840's Britain had just completed about a hundred years of industrial revolution, financed in the first place on the profits of foreign trade. These profits had steadily increased, and to them had been added the enormous profits arising from the new steam-driven machine industry.

This accumulation of new capital was made still greater by the big increase in the number of the working population. In 1751 the population was 7,250,000. In 1831, it was 16,539,000. At the same time, the standard of living of the working people had risen very little. George Stephenson's own conditions of work as a young man showed that he was glad to get twelve shillings for a week of twelve-hour working days. As engine-wright of the Killingworth collieries with their 160 miles of working galleries, he received only £100 per annum, in spite of his very large responsibilities.

The navvies who laboured on the early railways received 2*s.* 6*d.* a day for ordinary work, and up to 5*s.* a day for dangerous and difficult work such as tunnelling. In Devon, for example, they were housed in turf huts by contractors who charged them 3*s.* a week for a room. The construction sites usually being out in the open country, the men bought their food and materials from tommy shops run by the contractors, who put out 'a great deal of inferior stuff'.

There were no welfare arrangements other than those provided by the men themselves. They organized their own sick clubs, which were especially necessary because of the large number of accidents. The percentage of killed and maimed was very high, and after they had passed their prime they were no longer strong enough for the work. Not having learned a craft, and having no social insurance, many of them died in wretched poverty.

Trade unions had not yet sufficiently developed to secure for the mass of industrial workers a fairer share of the vast new wealth. Consequently, a very large part of this lay in the hands of a comparatively small group of persons. Within this group, there was a yet smaller minority of progressive industrialists who wished to use their capital for the improvement of technique as well as the increase of profits, but a much larger majority of middle-class business and professional people who were concerned only with handsome dividends.

This accumulation of wealth was stimulated by the government policy under Sir Robert Peel, reducing the cost of food, and keeping the cost of borrowing money very low; and it was helped by such fortunate circumstances as a particularly good harvest in 1842.

Thus there was more money available for speculation by the investing classes than ever before. A large section of these were willing to invest in projects of which they had no technical knowledge. They were prepared to swallow any plausible argument in their favour.

Following on the success of the Liverpool and Manchester Railway, scores of projects for local railway systems were launched, and construction started. The dominant groups of shareholders in most of them were local businessmen.

A few engineers of constructive imagination, of which George Stephenson was the chief, had envisaged a national system of trunk lines joining together the great industrial and financial centres. He foresaw the difficulties which would arise when all the local independent railway systems grew so that they came into contact with each other. One of the reasons why he was so doggedly determined in favour of the 4 feet 8½ inch gauge, was that its general adoption would reduce these future organizational difficulties. But Stephenson was not a politician and financier. He saw that there should be a national railway system, but he did not know how it could be brought into being.

Little was to be expected from the shareholders of the local railways. They regarded their lines as their private property. What right had anyone to tell them what to do with their own? Some statesmen could see, however, that some way of co-ordinating the railways was imperative. In 1844, Gladstone, then a young minister and President of the Board of Trade, energetically prepared a bill for controlling the railways and beginning the process of welding them into a system. It was strongly opposed by the railway interests in the

House of Commons, who succeeded in emasculating the bill by insisting on the removal of twenty-four of the main clauses.

Gladstone resigned shortly afterwards, having told Peel that he felt embarrassed by his family connections with railways (his relatives were among the most important shareholders of the Liverpool and Manchester Railway).

It was evident that Gladstone felt unable to meet the arguments of the railway interests, who expressed their case in his own language of *laissez-faire*, or that he had not the moral strength to do what he knew to be right, in spite of its conflict with his political ideas.

As the conventional statesmen, typified by Gladstone, could not, or would not, systematize the railways, this national necessity had to be carried out by some other agency. In historical situations of this kind, the alternative agency is usually an equivocal character of strong personality, and in the case of the British railway system, it turned out to be a York linen draper named George Hudson.

He was a farmer's boy born in North Yorkshire in 1800, who had become a draper's assistant in York, and married into his employer's family. He very carefully tended a delicate relative who soon died, and left him, at the age of twenty-seven, a fortune of £33,000. He sought to raise his social standing by energetic support of the local Tories, and, unlike many of the Tory gentlemen, was not cast down by the rout of their party in the reform election of 1832.

Hudson fought back, and successfully organized the Tory campaign for the recovery of one of their seats in the election of 1835. He used the toughest methods, which led to a parliamentary inquiry, but the committee came to the conclusion that there was little to choose between the two sides in the nicety of their electioneering, so the election was not revoked. Hudson secured the most loyal confidence and support from the local Tory aristocrats, who helped him to found a bank, and obstinately stood by him through the most unsavoury storms of his later career. His natural aptitudes enabled him to learn a great deal about snobbery and the arts of manipulating public opinion from his early political experiences. He emerged as mayor of York, and chairman of his own bank, with many friends among the Yorkshire landowners. With the rise of the railways, he became a member, and treasurer, of the local committee to agitate for railway connections for York.

He had acquired an estate near Whitby, and as a local proprietor, attended the opening of the little horse-railway from Whitby to Pickering. George Stephenson had been invited to be present, and Hudson made his acquaintance. The two men took to each other at once. Stephenson spoke broad Northumbrian, and Hudson broad Yorkshire. Both had started life as village boys. Stephenson felt at ease with him, and admired his swift understanding and capability in business. Hudson learned from Stephenson the grand idea of a national railway system, and the necessity for amalgamation of the innumerable small companies that had become established. Hudson saw to the bottom of the souls of the greedy majority of railway investors. He was himself a local businessman, a typical member of their class. At the same time, he had the imagination to respond to the ideas of Stephenson. He would create a railway system for the whole of the country, with himself at its head. He would achieve Stephenson's main conception through the exploitation of the railway speculators' own cupidity.

He became chairman of some local railway companies which could not fail to prosper in the very favourable economic situation, and with his command of methods of publicity built up a reputation as a financial genius.

He played on the sentiments that the wonderful railway development aroused, the release of the individual from the locality, the romance of speed, and the new possibilities of health brought by seaside holidays for millions of the population. He started the development of Scarborough as a popular holiday resort.

Hudson organized the opposition which defeated Gladstone's attempt at railway control in 1844. It is said that Gladstone gave way after a private meeting with Hudson. In the following year, Hudson himself appeared in Parliament as member for Whitby, and sat on the Front Bench.

As the chairman of booming railway companies, he was invited to join the boards of those which were running at a loss. He set up a great establishment in London. As soon as he secured control of a company which was losing money, it began to pay handsome dividends. The majority of the shareholders were delighted with him, and roared his praises.

The Duke of Wellington called on him and informed him that his sister had bought some railway shares which had proved very disappointing. What did he advise about it? Hudson instantly grasped the situation, and assured the Duke that he would see what he could do. The Duke departed, and Hudson ordered the worthless shares of the rickety company to be bought. Their value rose, and when it had reached par, he returned the original sum to the Duke's sister.

The Duke called on him again, and thanked him warmly, and asked whether there was anything he could do for him. Hudson told him that because of his plebeian origin his daughter was being cold-shouldered by the other girls at a fashionable school at Hampstead. The Duke said he would call on the young lady, so that when the quality of her friends was perceived, there would be no more trouble of that kind.

The Duke duly called at the school. The maid who had opened the door informed the thunderstruck headmistress that the Duke of Wellington had arrived to present his compliments to Miss Hudson. The young lady was produced, the Duke gave her a bouquet and walked round the garden with her, making polite conversation, and then took his leave.

In 1847, when the Prince Consort was installed as Chancellor of the University of Cambridge, Hudson personally organized the special train which took the Queen and her husband from London to Cambridge. He erected splendid pavilions for the Queen's comfort, and had luxuriously upholstered special carriages for her. He personally saw her on to the train at London, and jumped down at Cambridge, rushing down the platform to open the door for her to step out. Then he offered her his arm, which she took, and led her into the pavilion. He secured from the Queen thanks in writing for his exemplary arrangements.

George Stephenson was pleased to be in his company on special occasions. When the line from London to Newcastle was completed in 1844, a special train took a party of leading railwaymen over the route of 303 miles in a little over nine hours. Hudson acted as Master of Ceremonies, and behaved as the patron of Stephenson, whom he introduced at Newcastle for an ovation.

Meanwhile, Hudson was paying dividends out of capital, taking the profits from one company to cover the losses of another, and issuing false balance sheets. Investors were only too glad to leave everything in his hands. He ruthlessly pushed through amalgamations of the little companies, mixing up all their accounts, for no other person knew what they were. Once the eggs had been scrambled, they could not be unscrambled. While Hudson was managing the shareholders, Robert Stephenson was the technical pilot of the amalgamating bills before the parliamentary committees.

A frenzy of speculation arose, and became known as the Railway Mania. The newspapers were taking £14,000 of railway share advertisements every week. The new railways were the actual instruments for the distribution of the papers and of the new prospectuses, genuine and chimerical.

By November 1844, the aggregate capital of projected lines amounted to £563,203,000, in a year when the whole budget of the British Government was only £50,000,000.

A public testimonial to George Stephenson was proposed, and Hudson indirectly suggested one for himself. The Stephenson testimonial was side-tracked, while a grateful public gave Hudson £30,000. Emily and Anne Brontë each subscribed one of these pounds.

Hudson diverted the railway centre of the North from George Stephenson's suggestion of Leeds to his own city of York.

By 1849 Hudson's manipulations could not be concealed. or bluffed out, any longer. His defalcations became palpable, and he fled to France to avoid his creditors. He wasted about £30,000,000 of the nation's wealth, but he was not prosecuted, partly because of defects in the existing company law, and because too many important people were implicated. After years of exile, he returned to England, where his admirers presented him with a pension of £600 a year, and he was re-elected chairman of the smoking-room of the Carlton Club. He never showed any feelings of guilt, for he contended that by achieving the amalgamations, he had performed a social service. He had only used the methods which were necessary for the purpose, and he felt injured by the rude things that many of his former admirers were now saying about him. Owing to the methods of financing their construction, insisted upon by the nineteenth-century *laissez-faire* businessmen and speculators, the British railways cost about twice as much to build as they ought to have done. This over-capitalization strengthened a policy of low wages and cutting of expenditure on improvements, which has dogged them ever since.

George Stephenson had begun to retire from leading railway managements in 1840. He started a colliery at Clay Cross, foreseeing that the Midlands would in the future supply London with coal by rail. He built a fine house at

Tapton near Chesterfield, and spent much of his time trying to grow hothouse pineapples and straight cucumbers, feeding stock, and making agricultural experiments.

'Hudson has become too great a man for me now. I am not at all satisfied at the way the Newcastle and Berwick line has been carried on, and I do not intend to take any active part in it. I have made Hudson a rich man, but he will very soon care for nobody, except he can get money by them.' George Stephenson and his son shrewdly evaded being financially involved in Hudson's schemes, even though Robert retained his connection with thirty-four lines.

Hudson at the height of his notoriety was fawned upon by dukes, earls, baronets, and speculators from every section of society for financial tips. He gave huge parties at his country mansion in Yorkshire. Carlyle reported that he would first meet his guests just before dinner, drink 'largely of champagne, with other wines'; and then 'ate nothing at all, hardly an ounce of solid food', then he 'tumbled into bed, worn out with business and madness'. He left his house early in the following morning, and his guests were dispatched 'by express trains over all the island'.

There is a parallel between the son of Stephenson and the son of James Watt. Roll has remarked that James Watt and Matthew Boulton made the steam-engine a commercial possibility, but that their sons manufactured it. George Stephenson made the railway a commercial possibility, and his son converted their construction and manufacture into an industry. Their sons were less original than themselves, but were better educated, and ultimately became more conventional. In each case the son made a fortune about three times as large as that of his father. The function of the sons was to assimilate the inventions of their fathers into the service of the existing social system. The fathers were primarily creators, while their sons were primarily well-educated industrial managers.

In his last years, George Stephenson was fond of visiting Mechanics' Institutes, and talking to the young mechanics who were studying in the evenings (after a ten-hour day), in order to deepen their knowledge of science. He would gather them around him, and discourse on his youth, on thinking and experimenting for one's self, and on how seemingly insuperable difficulties could be overcome by dogged perseverance. He never saw any solution to the problems of life and society except through individual effort.

He was repeatedly offered a knighthood, and was invited to stand for election to the fellowship of the Royal Society, but he refused these honours, as he 'objected to the empty additions to my name'. He would have liked to be a member of the Institution of Civil Engineers, but this Institution insisted that he submit a 'probationary essay' (in less polite terms, submit to an examination) for membership, because he had never served an apprenticeship to the profession. He said that 'if he went in at all, he would go in upright, not stooping one inch', and so never became a member of the one engineering society he particularly desired to join.

George Stephenson died in 1848, and left a fortune of £140,000. In 1850, Robert Stephenson said that 'It seems to me but as yesterday that I was engaged as an assistant in laying out the Stockton and Darlington Railway. Since then, the London and Midland and a hundred other great works have sprung into existence. As I look back on these stupendous undertakings, accomplished in so short a time, it seems as though we had realized in our generation the fabled powers of the magician's wand.'

Nine years later, Robert Stephenson died, leaving a fortune of £400,000.

A monument to father and son was presently raised in Westminster Abbey.

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THOMAS ALVA EDISON

1847–1931

THOMAS ALVA EDISON was born on 11 February 1847, at Milan, Ohio, a village on a canal connecting Lake Erie with the eastern cities of the United States. His adolescence coincided with the outbreak of the American Civil War, the great struggle between the slave-owning planters of the South and the industrialists and bankers of the North, as to who should rule the United States. He spent his most impressionable years during one of the greatest and most important struggles in history, and he grew up in the aftermath of the Civil War, amidst the disorder, but also with the hopes arising from the settlement of the main lines of the future America.

On his father's side his ancestors were Dutch. They were descended from millers who had lived beside the Zuider Zee, and emigrated to America in 1730. Different members of the family chose different sides in the War of Independence. One Thomas Edison became a clerk of the Secretary of Congress, with the authority to sign United States bills of credit. Though he could give credit on behalf of his country, he did not receive his salary regularly, owing to the difficult financial situation of Congress. He ran into debt, and the traitor Benedict Arnold tried to exploit his embarrassment by offering him a bribe to commit treason. Thomas Edison reported this to Congress, which passed a resolution commending his fidelity. This did not, however, ensure the payment of his salary. He was presently jailed by a creditor, and died in poverty. He lived to the great age of 104.

While Thomas Edison was working for Congress, his relative John Edison was fighting for the British. He had an estate in Essex County, and fled to New York before the supporters of Congress. He guided Lord Howe's troops in their pursuit of Washington through Jersey. He was captured by the Americans, and held in prison for a year before being tried for high treason. He was convicted, and sentenced to death. His wife persuaded Thomas Edison to intervene against the sentence. Thomas did so successfully, and John Edison was released on parole.

When the War of Independence was over, John Edison was one of 35,000 who remained loyal to the British, and were transported by the British Government to Nova Scotia. He, with his wife and seven children, preferred to face the primeval forest rather than submit to the Congress.

John Edison remained in Nova Scotia for about twenty years. His eldest son Samuel had a boy whom he named Samuel junior, born in 1804. About 1811 the Edison family migrated by ox wagon to a place on the Canadian shore of Lake Huron, where they founded a village called Vienna. When the war of 1812 between the United States and England broke out, Samuel Edison raised a company of Canadian volunteers to resist American invasion.

John Edison died in 1814. He had been a tall, strong man, and his sons were like him. Samuel became the head of the family, and his boy Samuel junior grew up into another tall, strong, athletic man. Samuel junior kept an inn in Vienna, and in 1828 he married an American girl called Nancy Elliot, who came of a family of ministers and Quakers. She had been better educated than most of her neighbours, and was the village schoolmistress. Nineteen years later, she gave birth to Thomas Alva Edison.

But long before the future inventor was born, Samuel junior exhibited the characteristic Edisonian intransigence. John Edison had fought against the United States; Samuel junior took up arms against the Canadian Government. He joined W. L. Mackenzie in his revolt of 1837, and lent his inn at Vienna for conspiratorial meetings. Mackenzie attempted to seize Toronto, and Samuel marched to his support. But on the way he heard that Mackenzie had been defeated. He rushed back to Vienna, said good-bye to the family, and fled to the United States. He covered 180 miles on foot, pursued by Canadian militia and Indians, but eluded them. They had been put on to a false scent by old Samuel senior, who remained in Vienna.

Samuel junior found his way to Detroit and took part in some more sallies against Canada. Then he searched for a new home, this time in the United States. He settled at Milan, which was a centre of grain transport carried by canal, before the construction of the Ohio railways. He started a business making wooden shingles for roofing houses. He brought his family to Milan and built a durable brick home for them. Presently, in 1847, after they already had a large family, Thomas Alva was born.

With the construction of the railways the grain trade of Milan declined, so Samuel moved with his family to Port Huron in 1854. He became a dealer in grain and cattle-feed. He built a house with a magnificent view over Lake Huron, and erected an observation tower a hundred feet high, through which visitors could survey the panorama with a telescope, for a small fee. As a little boy, Thomas Alva was in the habit of observing things through a telescope.

When the American Civil War began, Samuel, true to the Edison tradition, was in opposition. Though living at the extreme North of the United States, he publicly supported the South. He inherited the Edisonian physical strength, for at the age of sixty he could easily walk the sixty-three miles from Port Huron to Detroit. He died at the age of about ninety years, and several of his sons, Thomas Alva's brothers, lived to over ninety years. The inventor came of a family of exceptional physical strength, endurance, pioneer resource, and obstinacy.

As a child at Milan, Edison played around the canal and shipyards. He asked questions incessantly, which was thought to indicate that he was sub-normal. As he had an exceptionally large head, it was assumed that his apparent stupidity was due to brain disease. His backwardness was probably due to congenital hardness of hearing, though Edison himself said that his deafness was caused by an accident when he was a boy. He made slow progress at school and owed most of his early education to his mother. At the age of nine, he came across a simple textbook of physics and chemistry, which fired his interest in science. He began making experiments, and collected a few pieces of apparatus in the cellar of his home. Edison always said that he felt himself more of a chemist than a physicist. He liked trying many experiments rather than working out general ideas.

Owing to his alleged dullness, he did not attend school regularly, and had all the more free time for playing with his chemicals and bits of apparatus. He collected pieces of wire, and copper, and zinc, and made voltaic cells. His father was quite prosperous and he had plenty of pocket-money for buying things. In this period of rapid construction there were plenty of materials about.

Edison increased his pocket-money by doing odd jobs. He hawked vegetables from his father's vegetable garden. Then he thought of selling newspapers and sweets on the local railway trains. He was not sent to earn money; he did this on his own initiative.

He began newspaper-selling in 1859, just before the outbreak of the Civil War. He left Port Huron each morning on the 7.30 a.m. train for Detroit and arrived back at 9.30 in the evening. He sold papers until about eleven o'clock in Port Huron before going home. In a few months he had stalls in Port Huron for newspapers and fruit and vegetables, and engaged other boys to look after them. He was then twelve years old.

The express from Port Huron to Detroit had a little-used United States Mail baggage and smoking-car. The windows of the smoking-compartment would not open, so passengers found it stuffy and avoided it. Edison bought vegetables in the Detroit market, and put them in the U.S. Mail car. No one asked him to pay for the transport of these goods. Between 1850 and 1860, the United States railways were extended from 7,500 to 30,000 miles, and in this period of swift growth, doubtless nobody bothered about details.

As the Civil War developed, he found that the selling of newspapers became very profitable, and he dropped the vegetables. He made a profit of about eight to ten dollars a day. He spent much of his earnings on chemicals. He made a small collection of these in the unused smoking-compartment, and played with them during the train journey after he had finished selling his papers.

He had about nine hours a day in Detroit, where he spent much time looking for technical literature, and watching what was going on in the workshops of the Grand Trunk Railroad. He became acquainted with Pullman, who was at that time a small shopkeeper in Detroit, experimenting with his railway car.

The great increase of interest in newspapers during the Civil War suggested to him that he should start his own. He bought some type and set up his newspaper on the train. He called it the *Weekly Herald*. It was probably the first newspaper in the world to be produced on a train, and the London *Times* referred to it.

The *Weekly Herald* contained items about friendly engine-drivers, market prices, train services, war news, and local items. One of these under a *Birth* heading read: 'At Detroit Junction G.T.R. Refreshment Rooms on the 29th inst., the wife of A. Little of a daughter.' As a fill-up at the bottom of a column he had put in: 'Reason, Justice and Equity, never had weight enough on the face of the earth, to govern the councils of men.'

One day, in April 1862, on arriving at the newspaper offices at Detroit, he found them surrounded by an excited crowd awaiting news of the Battle of Shiloh, which proved to be the decisive battle of the Civil War. The first bulletins announced that there were 60,000 casualties. (Actually, there were 25,000.) Edison noticed the desperate interest of the crowd in the news. 'I then conceived the idea of telegraphing the news ahead, went to the operator in the depot, and by giving him *Harpers Weekly* and some other papers for three months, he agreed to telegraph to all the stations the matter on the bulletin-board.'

He bought a thousand instead of the usual hundred copies of the Detroit paper, and started on the journey home. At the first stop, Utica, there was a stampede for his papers. 'Then I realized that the telegraph was a great invention.' At subsequent stops he raised the price of his papers, and at Port Huron he charged a quarter of a dollar for them, making what, for a boy of about fifteen was an immense sum.

This experience with the effects of the electric telegraph, and his acquaintance with the railway telegraphers, stimulated his interest in telegraphy. The electric telegraph was essential for the safe operation of the new railways, and indeed for holding the United States together as a nation. Without its almost instantaneous communications, the United States could not have developed quickly, and probably not at all as a unit.

Edison got one of the railway telegraphers to teach him telegraphy. He made his own set of instruments in a gunshop in Detroit, and practised on them sometimes as much as eighteen hours a day. He tried to set up his own telegraph business on a line about a mile long, but nobody wanted to send messages over such a short distance, so he sought a job as a telegrapher. This was not difficult to get, owing to the absence of most of the regular telegraphers at the war. He began at the age of fifteen, working all day at the office, and practising at home until 3 a.m. His first appointment was at Stratford, on the Grand Trunk Railroad, in Canada.

He spent a lot of time experimenting with his instruments, and he made his first invention at Stratford when he was sixteen. Night operators were required to send an hourly time-signal to show they were awake. Edison devised a clock to do this for him automatically. The device was similar in principle to a later apparatus for calling district messengers to a central office.

Edison lost his job at Stratford because of a failure in the signalling of two trains, which nearly ended in an accident. He was called to Toronto for an inquiry, and ran away while it was proceeding.

He then began five years of wandering life as a 'tramp operator'. He worked at stations through the central states, from Detroit to New Orleans. The telegraphers were absolutely essential for the operation of the huge half-organized country. They were strongly organized, and extremely independent. They were the exponents of electricity, the wonderful new force of the future, and they attracted to their ranks progressive and enterprising young men. Through their connection with the railways, they had little difficulty in hitch-hiking over all the country.

The telegrapher's work was highly skilled, owing to the primitiveness of their instruments. They earned high wages, but the intensive telegraphing with imperfect instruments strained their nerves. The railways and telegraphs had only recently been built. Frontier conditions prevailed, and were intensified by the war.

At Indianapolis Edison devised an instrument to take press reports very quickly, and then play them over slowly at a later time, when business was not so pressing. This repeater consisted of a disc of paper on which the messages were registered by indentations along spiral curves. It was from this instrument that he subsequently evolved the idea of the phonograph.

At this time, Edison was a thin, badly dressed, uncouth, and unpopular youth. He was always trying experiments with his instruments and batteries, and playing jokes on his colleagues by giving them electric shocks.

He was at Cincinnati when the news of Abraham Lincoln's assassination came through. Writing of this event, Edison recalled how he saw an immense crowd gathering in a street outside a newspaper office. He called the attention of his fellow-operators to it, and sent a messenger to find out what it was all about. The messenger rushed back and shouted: 'Lincoln's shot.' All the operators looked at each other in stunned amazement, and their first thought was to discover who had transmitted the message. It turned out that one of them had telegraphed it to the newspaper office, working so mechanically that he had not taken in what he was sending. Cincinnati was then celebrating the conclusion of the war, and it was noted with horror that a brother of the assassin Booth was playing in the local theatre. The unfortunate man was immediately hurried away, and the gay decorations of the city were changed overnight to mourning drapery.

While Edison was at Cincinnati he often went to the theatre. He was particularly fond of *Othello*. He used to earn a few extra dollars copying plays, in those days before the typewriter.

Edison obtained promotion to the most highly paid class of operators by black-legging when his colleagues were on strike. He was not always able to get jobs. He wandered through the offices at Memphis, and nearly starved in Alabama, and arrived in Louisville on a frosty day, wearing only a linen duster suit.

When the telegraphers returned after the war, their life rose to a new height of wildness. They found civilian occupations boring. They flung inkwells at each other in the offices, and followed them up with revolver shots. During the nights they went into the neighbouring gambling-rooms, where food was free to everybody. Edison described how on one occasion he and a companion went 'over to a gorgeously-furnished faro-bank' to get their supper. Twenty keno-rooms were running. 'One of them that I visited was in a Baptist church, the man with the wheel being in the pulpit, and the gamblers in the pews.'

While Edison was at Cincinnati during the Civil War, he had to send an urgent message from Washington to General Thomas, who was in danger of being captured at Nashville. He tried to make a roundabout connection through Louisville, but could get no answer from that office. It turned out that none of the three operators there was on duty. One had broken his leg, another had been knifed in a gambling saloon, and the third had gone to see a man hanged and had missed the return train.

Edison was at Louisville for two years. He experimented with handwriting, and evolved a simple script which enabled him to take down messages very swiftly and clearly.

He wandered to Detroit and thought of emigrating to South America, but went back to the Middle West. He met an operator named Ellsworth, who had worked for the South in the Civil War, and had sent false telegraphic messages to confuse the Northern forces. He suggested to Edison that he should devise a method of telegraphing that could not be intercepted. From this suggestion, Edison later evolved his system of quadruplex telegraphy, by which four messages may be sent simultaneously on one wire. Ellsworth could not settle down to civilian life; he went to Texas and became a gunman and disappeared.

Edison went home to Port Huron in 1868. After a short time, he applied for a job in the Western Union office at Boston. When he presented himself, he was wearing trousers that were too short, worn-out shoes, a dilapidated butternut hat, and hair done in the cowlick style. He spoke in an uncultivated accent, chewed tobacco incessantly, and spat copiously. He was quite assimilated to the wild and raw society in which he had been living for the previous five years.

The Boston operators thought they would play a trick 'on the jay from the woolly West'. They arranged with friends in New York to send a very fast message, and then set Edison to receive it. With his special script he was able to receive very quickly, and easily kept up with the message. The New York operator began to slur words, and Edison guessed from the attitude of his colleagues what they were up to. He was used to slurring and other tricks, and was able to carry on in spite of them. Presently he took up his own key and transmitted to the New York operator: 'Say, young man, change off, and send with your other foot.'

While at Boston, Edison secured his first patent for an invention. This was for an electrical vote recorder, for use in Congress, so that senators could vote without leaving their seats. When he demonstrated it to the politicians at Washington, they laughed at him. They explained that they did not want quick voting, but slow voting, to assist in filibustering.

After this experience, Edison decided that he would never again invent anything for which the market was not evident. Thenceforth, he subordinated invention to the demands of commerce, and tried to convert it from an activity of fantasy into one of prosaically trying to meet a need. As he said later: 'Invention is one per cent inspiration and ninety-nine per cent perspiration.'

Edison's next invention was a stock-ticker, for registering the latest stock-exchange quotations in offices. The first machine of the kind had been introduced in 1867. It was a simplified form of printing telegraph, which was installed in each broker's office, and operated from a central transmitting station in the stock exchange. Edison's improved stock-ticker was installed in a number of Boston offices, but as Boston was not the centre of stock-exchange transactions, it was not very profitable. Edison saw that he would have to get them adopted in New York, if he was to make much money out of them.

Edison connected his stock-tickers with brokers' offices by simply slinging wires over the intervening buildings. He told the occupants that he had come to repair existing wires, and added a new one of his own, without any comment.

While at Boston, he worked on duplex systems of telegraphy, in which two messages are sent simultaneously over one wire. He spent his earnings on experiments, and ran into debt. Deciding that he might do better in New York, he moved there in 1869, and arrived nearly starving. He carefully studied what was the best value in food, and lived on apple dumplings and coffee. He was now twenty-two years old.

He obtained a job as telegraphist in the Western Union office, and being without lodgings, slept in the battery room of the Gold Indicator Company. This company had a system of tickers for transmitting the variations in the price of gold to the offices of the New York brokers and speculators. Having invented his own ticker, Edison examined those of the Gold Indicator Company with a professional eye, and mastered all their details. This knowledge very soon enabled him to start his main career of invention.

The result of the Civil War had determined the ascendancy of the Northern capitalists. The bankers of New York were financing the enormous new railways, mines, and canals, and the huge transactions in land which their development required. The possibilities of construction were almost beyond imagination, and the population lived in a riot of anticipation and hope. The financing of the Civil War had accustomed the Americans to think in new orders of millions. The Northern finances had been managed by Jay Cooke, who issued vast quantities of paper money to meet war loans, and provide gratuities for the demobilized soldiers.

Hundreds of thousands of men who would not normally have had quantities of ready money, found themselves with considerable sums in hand. The immense demands and possibilities for real construction, and a profusion of projects of every degree of value, combined to produce an orgy of speculation.

The most prominent figures in this turmoil were the millionaires who controlled the railways. The United States Government had stimulated railway development by granting huge amounts of free land to the railway companies. The railway millionaires not only controlled the railways, but all these estates, and their agricultural, forest, and mineral wealth besides. They used their financial power for manipulating share values on the stock exchange, and added enormous profits from these transactions to their other holdings.

In 1866, Drew, the treasurer of the Erie Railway Company, managed to acquire a large part of the shares of the company by an ingenious financial manœuvre which had not been thought of before. He retired from the field 'hated, feared, wealthy, and admired'.

Two years later a far more dramatic figure, Cornelius Vanderbilt, popularly known as the 'Commodore', who was the first to perceive the possibilities of combining the power of the individual with that of the financial corporation, conceived the idea of gaining control over all the railways serving New York City, and then holding up to ransom the trade of the city, which was a large part of that of the whole country. During 1868 he secured the control of all of the lines serving New York, except Drew's Erie. He then set out to annihilate Drew.

The two men were in complete contrast. Vanderbilt was loud, buoyant, and gay, fond of horses, wine, and women. He played whist, while Drew attended prayer meetings. Vanderbilt was the perfect 'bull', while Drew was the perfect 'bear'.

'Bulls' made fortunes by forcing up the prices of shares, whereas 'bears' made fortunes by forcing them down. The choice of method depended on individual psychology, 'bulls' generally being optimistic, and 'bears' pessimistic by temperament.

Vanderbilt first tried to capture his opponent by manœuvre, but Drew, who was lacking in imagination and could never have conceived such a scheme as Vanderbilt's, was very astute at defending an inside position. He outwitted Vanderbilt by chicanery of unequalled subtlety. The Commodore was forced to retreat, bellowing with rage at the affront before Wall Street. He now attacked Drew 'with the brute force of all his millions'.

Both of them bribed the judiciary, and sent trains with armed crews over their rival's lines. Sometimes they met in head-on collisions. The crews jumped off, closed together, and shot it out.

Among Drew's fellow-directors of Erie were Jay Gould and Jim Fisk. Gould equalled Drew in chicane and surpassed him in financial imagination, while Fisk was a freebooter who organized violence on behalf of Erie. Vanderbilt found Drew, Gould and Fisk too much for him, and was forced to retire defeated.

Meanwhile, the battle between Vanderbilt and Drew had produced unparalleled fluctuations in stock exchange prices. The huge new post-war speculating public had no satisfactory means for following the changes quickly. There was tremendous pressure on stock-ticker systems for transmitting prices.

The paper inflation had greatly increased the value of gold, so there was particular interest in gold prices. Gould and Fisk, after their triumph over Vanderbilt, conceived the idea of cornering all the gold in the United States, and forcing up its price to fantastic heights. They used the financial resources of the Erie Railway to begin this operation, and the price of gold began to fluctuate violently. Gold prices were announced by the president of a United States Government committee, who registered them on a board outside his office. The Gold Indicator Company was founded by Laws to transmit the official prices by telegraph to the brokers' offices.

The simple apparatus was unable to cope with the violent price fluctuations induced by the operations of Gould and Fisk. Now it happened that when Edison arrived in New York, and slept in the battery room of the Gold Indicator Company because he was penniless, the attempt to corner gold had just begun.

On the third day after his arrival, he was sitting in the transmitter room, when the transmitter broke down under the pressure at which it was working. Within a minute or two, the office of the Gold Indicator Company was besieged by messenger boys, screaming for the latest prices. Laws rushed in and asked what was the matter. The man in charge could not explain, but Edison, who had no right to be there, had made himself familiar with the works, and immediately told him that a contact spring had broken off and jammed two gear wheels. 'Fix it! Fix it!' shouted Laws.

Edison got the indicator working again within two hours, and suggested improvements in its design. Laws appointed him general manager on the spot at a salary of $300 a month. Edison had never before received such a salary, and three days earlier had been nearly starving.

A few months later, the efforts of Gould and Fisk to corner the country's gold reached a climax. They had used the resources of Erie to buy the comparatively small amount of gold ordinarily available, and thus created a stringency which could be relieved only by the sale of gold by the Government. This required the authorization of the President of the United States. The President at the time was General Grant, the victor of the Civil War. Though a superior general, he was quite feckless in the affairs of civil life, and thought politicians and financiers were wonderful.

Grant felt himself highly honoured by the attentions of Gould and Fisk. He shared the admiration of thousands of his fellow-countrymen for these miraculous financiers, and was persuaded by them to refuse to give the order to sell Government gold. Gould and Fisk bribed his relations to get him off to an inaccessible part of the country where he could not be got at, and made to change his mind.

The price of gold now soared to fantastic heights, because merchants engaged in foreign trade could not conduct their business without it. At the same time, Vanderbilt's railway shares slumped catastrophically.

While Vanderbilt was roaring back to New York by special train, Fisk was shouting bets in the gold exchange on the price which gold would reach, and boasted openly that the President of the United States was a member of his ring.

Legitimate business languished, and crowds of desperate gamblers surged from the exchange into the neighbouring taverns during the night.

In spite of Government opposition, the price of gold was driven still higher.

But on the following day, Friday, 24 September 1869, Government pressure began to be effective. Fisk was reduced to pure bluff, and insisted on paying for gold at 160, when it was offered to him at 135. When the Government sellers insisted on settlement, Fisk fled from the scene. Gould had meanwhile secretly withdrawn his own money.

By Friday night, transactions, totalling $500,000,000, had ended in inextricable confusion. All accounts were washed out, and speculators agreed to cut their losses.

On this notorious 'Black Friday', Edison was in charge of the Gold Indicator System. It fell behind in the morning, but by one o'clock he had made it catch up with the current prices.

Later in the day, Edison sat on the top of the Western Union telegraph booth, watching the crazy crowd. He saw one man grab a pencil and try to write a telegram for Boston. His pencil shot off the paper. He was too excited to write, and his telegram had to be taken down for him. Edison saw the banker Speyer go mad, and having to be held down by five men. The Western Union operator came to him and said: 'Shake, Edison, we are all right. We haven't got a cent.' Edison said that he felt very happy that he was not involved. Such occasions were very enjoyable for a poor man, but they happened rarely.

Edison knew from the telegraph messages that some sort of conspiracy existed between the Government and Wall Street. He saw Fisk, dressed in a velvet corduroy coat and fancy waistcoat. 'He was very chipper, and seemed to be lighthearted and happy. Sitting around the room were about a dozen fine-looking men. All had the complexion of cadavers. There was a basket of champagne.'

The scene was reminiscent of the British railway gamblers of 1845, with George Hudson at their head.

Six days after 'Black Friday', Edison went into partnership with F. L. Pope to design and operate telegraphic equipment and indicators. He advertised his intention to 'devote his time to bringing out his inventions'. Pope, Edison & Co. described themselves as 'electrical engineers'. It is said that this was the first time that the title was used in a professional sense, so Edison may be credited with the invention of the profession of electrical engineering.

Pope and Edison began by introducing a stock-ticker that would work on one wire. The president of the Gold & Stock Telegraph Company, Marshall Lefferts, was interested in it, and asked Edison to improve his equipment. Edison rapidly invented and patented several improvements. He devised the 'unison stop', by which all tickers could be returned to zero by a switch in the central transmitting office. This saved the expense of synchronizing the tickers.

Lefferts decided to buy Edison's ticker inventions. He invited him to call. Edison went to see him, determined not to accept less than $3,000. Lefferts asked him how much he wanted, but he lost his nerve, and asked Lefferts how much he would offer. Lefferts asked how $40,000 would strike him. Edison nearly fainted, but managed to stutter his acceptance. Before this experience, he had measured the value of an invention by the amount of effort it had cost him. Henceforth he would measure it by what it was worth to others.

Lefferts handed him, there and then, a cheque for $40,000. Edison had never received money in the form of a cheque before. When he presented it at the bank, the cashier refused to accept it because it was not endorsed. For a dreadful moment, Edison feared he had been swindled, and rushed back to Lefferts, and told him what had happened. Lefferts laughed at him, endorsed the cheque, and sent a clerk with Edison to the bank to testify to his identity. The cashier, seeing that Edison was naïve, gave him huge piles of small notes for fun. Edison took them home and dared not go to sleep while he had them in the house. Next morning he went to ask Lefferts what he should do with them. Lefferts laughed again, and told him to start a bank account.

By the following year, Edison, who was now twenty-three, had a factory with fifty workers, manufacturing electrical equipment, mainly tickers for Lefferts. His men worked in two shifts and he himself was there for both. He did not sleep more than a few half-hours each night. He drank strong coffee and smoked cigars almost continuously. In his first workshop Edison employed J. S. Schuckert and S. Bergmann, who subsequently founded the immense German electrical firms of Siemens & Schuckert, and Bergmann.

Throughout his life, Edison was able to attract and employ men of outstanding talent. Other very notable ones were A. E. Kennelly, the discoverer of the Kennelly-Heaviside layer, on which long-distance radio communication depends, and A. F. Acheson, the inventor of carborundum. Within a few years he had taken out forty-six patents for improvements of stock-tickers.

He worked with extreme energy on the development of the electric telegraph. The early instruments were hand-operated and worked slowly. Automatic instruments could work much more quickly. But at high speeds, various electrical effects, negligible at low speeds, grew to serious dimensions, and began to interfere with the clarity of the signals. The increase in electrical self-induction especially caused trouble. Edison invented a way of evading it; and exhibited his instrument at the Centennial Exposition of 1876. Sir William Thomson (Lord Kelvin) was the judge of the electrical exhibits, and recommended Edison's instrument for an award. He reported that 'the electromagnetic shunt with soft iron core, invented by Mr. Edison, utilizing Professor Henry's discovery of electromagnetic induction in a single circuit to produce a momentary reversal of the live current at the instant when the battery is thrown off and so cut off the chemical marks sharply at the proper instance, is the electrical secret of the great speed he has achieved....' Thomson described it as a very important advance in land telegraphy.

Edison introduced practical quadruplex telegraphy in

1874. It was his first major invention. By it two messages could be sent in one direction and two in the other, simultaneously along one wire. Two signalling currents were used, one which varied in direction, and the other in strength. Each of the currents may be made to send two messages, making four in all, by arranging that the outgoing signal current operates the receiver at the distant station, but not at the home station. It was done by connecting a dummy wire of the same electrical resistance and capacity as the main wire to the end of the main wire in the home station and arranging that it should cancel out signals that were not wanted.

Though Edison was always stressing the importance of inventing only things of commercial value, he was not a good businessman. He did not employ book-keepers until his accounts had become chaotic. In his early days he lost a great deal of money through employing a bad patent-lawyer. When he met Professor Nernst, the great German physical chemist, in later years, after his own work on the electric lamp, he enlarged on his favourite topic of the necessity for inventions and inventors to be businesslike. Nernst quietly listened to his strictures on the unbusinesslike qualities of professors. It happened that he had invented an electric lamp with a rare earth filament. It was never very successful commercially, because the filament had to be heated up before it glowed at its full strength.

Presently Nernst asked how much money Edison had made out of his carbon filament lamp, and Edison replied that he had not made anything out of it. 'I was paid $250,000 by the A.E.G. for my lamp', replied Nernst.

Edison's quadruplex and other telegraphic inventions much increased the speed and volume of commerce in the United States. Jay Gould offered one million dollars to the Edison company for them, as a move to force down the value of Western Union stock. When the offer had been accepted, he repudiated it.

Legal proceedings to recover damages from him continued for thirty years. Edison was involved in the earlier stages of this affair. He took part in secret negotiations with Gould, entering his house through the back door. Gould paid him $30,000 for his personal interest in the quadruplex invention, but refused to meet other obligations.

In later years, Edison, according to his policy of praising successful financiers used to express admiration for Gould, but in 1876 he had written bitter letters to Gould complaining that his dealings with him had been 'a long, unbroken disappointment'.

Within a few years, Edison worked simultaneously on fifty different inventions. He invented the mimeograph, or stencil. This was cut by a pen with a point which vibrated up and down, so that fine holes were made along the line of the letter. He invented a paraffined paper for wrapping sweets.

In 1876 Bell patented the telephone. In its orginal form, the transmitting current was produced by an iron disc made to vibrate in a magnetic field by the sounds of the human voice. The current was very weak, so it could transmit only a short distance.

Edison swiftly removed this limitation by his invention of the carbon transmitter. He placed a small button of carbon against the iron disc under the human voice. The electrical resistance of the carbon varied with the pressure on it. He sent a current through the carbon which varied in strength with the variation of resistance of the carbon, and connected it with a transformer, so that its voltage was raised to any desired degree. With this high-voltage current, transmission could be accomplished over great distances. This made the telephone, 'the little mother of the big trust', a practical invention.

At this time Edison was connected with Western Union, which was controlled by Vanderbilt. Western Union pirated Bell's receiver, and Bell pirated Edison's transmitter, Edison received a payment of $6,000 a year for seventeen years for his transmitter. He preferred this to receiving a lump sum of $100,000, for he was afraid that he would fritter it away in his passion for experiments and trying things.

Jay Gould now decided to attack his old enemies the Vanderbilts, by striking at the Western Union. He bought Page's electromagnetic relay, which was believed to cover all forms of relay. Western Union asked Edison whether he could move a lever at the end of a wire, without using a magnet. He immediately produced a relay consisting of a lever resting against moistened chalk. He had discovered that when a current was sent through moistened chalk, the chalk became slippery. Hence, when a current was sent through the wire, the lever slipped on the chalk. This patent enabled the Vanderbilts to evade the patent owned by Jay Gould. For the invention of this armament of financial warfare, Edison received another $6,000 a year for seventeen years.

This invention was also used for fighting Bell's patents in England. When the Edison company set up its telephone system in England, it was opposed by the independent Bell company, who refused the use of their receiver. Edison made a strange telephone receiver, in which one end of a rod was placed against a diaphram, and the other on a moistened chalk cylinder. When the cylinder was rotated it rubbed one of the ends of the rod. If the current from the telephone wire was sent through the moistened chalk, the rod slipped a little, and the vibrations communicated to the diaphragm made it act as a loud-speaker.

This enabled the Edison company to resist Bell. They came to terms, and amalgamated to fight the British Post Office. The amalgamated companies paid Edison $150,000 for his patent rights.

Edison's London staff included a young man named G.

Bernard Shaw. He used his experiences in his demonstrations of the fearsome early telephones to prospective purchasers in his novel *The Irrational Knot*, which he wrote in 1880. It was his first published work. The hero was an American electrician, Edward Conolly. He was depicted as very competent and thorough, in contrast to superficial English aristocrats educated at Eton and Oxford. In the preface to his 1905 edition, Shaw described the young men whom Edison sent to his London office. They were hopeful, ignorant, and profane. They were proud of American ideals of liberty, and bore without a word the harshest bullying from superiors. They tackled difficulties with great energy, and were saved from much wasted effort by English colleagues who knew more, but had less initiative.

They were, indeed, widely different from Conolly. Nevertheless, it seems that Shaw found in the American electrical inventors the suggestion for a new type of character with which the traditional English ruling classes could be effectively contrasted.

Shaw said that the chalk receiver made loud almost unintelligible noises. A speaking-tube was rigged up, and a man shouted down it from another room, to make sure that the listener heard something he could understand, whether or not the chalk receiver itself was intelligible.

Edison married for the first time in 1871. His wife was Mary Stillwell, whom he had first met as a schoolgirl sheltering from the rain on the doorstep of his laboratory. Their first child, a daughter, was born in 1873.

Edison sought a more convenient place for a new laboratory and home. He moved to a quiet place called Menlo Park, about twenty-five miles from New York, in 1876, being then twenty-nine years old.

His Menlo Park laboratory was a new kind of institution. It was the first entirely designed for invention as a profession. It was the germ from which the modern industrial research laboratory arose, and the system of organizing investigators into a team, in order to solve industrial research problems.

Edison remained at Menlo Park until 1884, when his first wife died. The eight years were spent in unparalleled inventive activity, and were one of the formative influences on the direction and character of technological progress in the following century. At Menlo Park he undertook to attempt to make any kind of invention of which he could see the practical significance. His carbon telephone transmitter was his first major success in the new laboratory.

Then, in 1877, came his greatest invention, the phonograph, or gramophone. It arose out of his automatic recording telegraph, in which messages were recorded by making indentations in a paper disc. When the paper disc was rotated, the indentation raised a little lever up and down, which could transmit Morse messages at a very high speed. It was noticed that when the paper disc was rotated very rapidly, the lever gave out a musical note. Edison reasoned that if the disc could play a tune, then it ought to be able to reproduce the human voice.

He devised a horizontal cylinder covered with tin foil. A diaphragm with a needle was fixed above it, so that when the diaphragm was spoken into, its vibrations caused the needle to make indentations in the tin foil. While the experimenter was speaking, the cylinder was slowly rotated, so that a groove of indentations was made on the foil. The design was very simple, and was costed in the workshop at eighteen dollars.

When the machine was made, Edison shouted into the diaphragm: 'Mary had a little lamb'. Then he played it back. The sentence was reproduced perfectly. Edison said that he was 'never so taken aback' in his life. Experience had made him very wary of initial successes, but it seemed certain that this one would prove to be permanent.

His genius is seen in its full power in his specification of the uses of the phonograph, drawn up in 1878:

> 1. Letter writing and all kinds of dictation without the aid of a stenographer.
> 2. Phonographic books which will speak to blind people without effort on their part.
> 3. The teaching of elocution.
> 4. Reproduction of music.
> 5. The 'Family Record', a registry of sayings, reminiscences, etc., by members of a family in their own voices, and of the last words of dying persons.
> 6. Music-boxes and toys.
> 7. Clocks that should announce in articulate speech the time for going home, going to meals, etc.
> 8. The preservation of languages by exact reproduction of the manner of pronouncing.
> 9. Educational purposes; such as preserving the explanations made by a teacher, so that the pupil can refer to them at any moment, and spelling or other lessons placed upon the phonograph for convenience in committing to memory.
> 10. Connection with the telephone, so as to make that instrument an auxiliary in the transmission of permanent and invaluable records, instead of being the recipient of momentary and fleeting communication.

The phonograph was not very quickly perfected as a practical invention. Edison returned to it in 1888. After intensive efforts, including work on it continuously for five days and five nights, he improved it greatly.

Edison's most important invention, though not his most original, was the first practicable carbon filament electric lamp. He began work on this in 1878, at the suggestion of his friend Professor Barker, who pointed out to him the need for electric lights of moderate power for rooms and offices.

J. W. Swan of Newcastle-on-Tyne had made a carbon electric lamp in 1860. In 1878 he exhibited an electric lamp consisting of a carbon rod raised to incandescence in a vacuum, and in 1880 patented the process of heating the carbon filament during the exhaustion of the bulb, in order to drive out the occluded gases. He did not, however, produce a commercially successful lamp. When Edison introduced his lamp into England, he found that he could not evade Swan's patent, so he came to terms with him, and their lamps were manufactured under the name of Ediswan.

It was necessary to work out a process by which reliable lamps could be made on a large scale, and to study the problems of electrical supply which would arise if a satisfactory lamp could be produced. Edison made a thorough study of the main aspects of illumination. He examined the economics of the gas-lighting industry, to see what competition would have to be overcome from that quarter. He worked out how much electricity would be needed for an electric light system of a given size. He investigated the price of copper for wiring, the problems of dynamo design, and electric current distribution systems.

Edison and his assistants worked out the amount of radiation from filaments coiled in various shapes. High voltages and low currents were desirable in order to reduce the amount of copper in the supply cables. A fine filament was desirable, because it became incandescent with one-eighth of the current required for a filament twice as thick.

Meanwhile, he made a determined attack on the problem of carbon filaments. He had learned much about carbon from his experiments with the carbon for his telephone transmitter. He tried thousands of substances containing carbon, from tar to cheese. Ultimately, he found that bamboo fibres gave the best filaments.

The invention of a practicable electric lamp involved the economical manufacture of glass bulbs, the development of industrial vacuum technique, vacuum-tight joints, interchangeable lamps and sockets, wiring systems, and current meters.

He designed and built the first central electric power station. It was not yet clearly understood whether a strong electric current could be split and distributed through thousands of little lamps. Many experts thought that the whole system would fuse when the dynamos began to supply the strong current from the central station.

It was believed by many that the internal resistance of the dynamo should be about the same as that of the distribution network. This was a fallacy, but before it was generally understood, Edison decided to introduce big dynamos with very low internal resistance, which turned out to be correct.

He erected the first central electric power station. This was in New York. With it, he introduced the sale of electricity as a commodity. Factories employing many thousands of men were required to make the new electrical equipment.

The fundamental theoretical solutions of some of the main problems of dynamo design and electrical distribution raised by Edison's electrical power supply system were found by Professor J. Hopkinson, the great English electrical engineer.

The Edison electricity supply stations provided scope for a new generation of engineers. One of the engineers at the Edison power station at Detroit was a young man named Henry Ford. The future motor magnate was employed for many years by the Detroit Edison company, and during the spare time of seven of them, he made his first motor-car. Young Ford was brought to Edison's attention, and received his first important encouragement from the great inventor.

In later years, Edison and Ford, and one or two other famous inventors, used to go on an annual camping expedition. They were supposed to be recommending the simple life, and enjoying themselves. How much, in fact, they did enjoy themselves is uncertain. They were always accompanied by a considerable group of journalists, who reported their proceedings daily in detail. What was certain was that both of them obtained thousands of columns of free publicity by it every year.

The most remarkable scientific outcome of Edison's work on the carbon-filament lamp was his discovery in 1883 of the Edison Effect. This was his single important contribution to pure science. He noticed that when the inside of the glass bulb of a carbon filament lamp became blackened with age, through the gradual deposit of the carbon from the filament on to the glass surface, the blackening was not uniform. It was less in the region where the plane of the filament intersected the bulb. This suggested that one leg of the filament shielded the inside of the bulb from atoms of carbon shot off from the other leg of the filament.

The English electrical engineer, J. A. Fleming, who was at the time consultant to the Edison companies in London, thoroughly investigated the phenomenon. The effect was due to the emission of electrons from the hot filament. He utilized it to make a sensitive valve, which would allow a current to go in one direction, and not in the other, and applied it to the detection of the weak currents produced by radio waves. This was the origin of the radio valve.

In 1897, when the electron was discovered, it became evident that the Edison Effect, on which the radio valve depends, is due to thermionic emission, to the ejection of electrons from the carbon filament owing to its high temperature.

Edison made no direct contribution to radio communication. But in 1885 he patented a system of wireless communication by electrostatic induction. He placed two high masts at a considerable distance apart, and fixed a metal plate on the top of each. One plate was charged to a high voltage, producing an electric field which could be detected on the plate at the receiving mast. These two plates on the tops of high masts were the first electrical aerials. When radio telegraphy was introduced some years later, the inventors found that they could not use aerials without infringing Edison's patent. Rivals of the Marconi Company tried to buy it from him, but in 1903 he sold it to Marconi.

After the death of his first wife in 1884, Edison married again in 1886. He was thirty-nine and his new wife was twenty. The character of his life and work changed profoundly. The ruthless obsessional concentration of his early years was replaced by more conventional behaviour. His second wife had been well-educated and belonged to a more conventional social stratum.

Edison was represented by the advertising departments of his firms, and by industry generally, as a national character, a successful American businessman who had made money out of invention, and passed his later leisured years in cultured and benevolent activities. Edison himself made little effort in his personal life to live up to this picture.

He made many inventions in his second period, but they were less brilliant than those of the first, and contained more failures. He began to think about the cinema at the end of his first period. In his earliest notes on this subject, made in 1887, he wrote that it should be possible to devise an instrument which would do for the eye what his phonograph had done for the ear, and that 'by a combination of the two, all motion and sound could be recorded and reproduced simultaneously'. He forecast that in coming years grand opera would be produced without any material change from the original, by artists and musicians who were long since dead.

The realization of his cinematographic inventions belonged to his second period. They were in part brilliant, and in part seriously lacking. After Eastman had invented the flexible photographic film, Edison devised the first cinema camera. He made holes along the edges of the strip of film, so that it could be moved forward by means of toothed wheels, and fixed the width of the film and the size and distance apart of the holes, and these have remained the standard for cinema films ever since.

Edison made the first commercial motion pictures. His films, after they had been developed were run inside a box. The spectator applied his eye to a peep-hole, and then saw the pictures recorded by the films. These kinetoscopes were set up in fairgrounds in 1891. Edison created the first motion-picture studio for making his films, but he did not create a film-show which could be seen by mass audiences. Just as he had refused to believe the reports of his phonograph salesmen in Germany that the people demanded classical music, so he failed to introduce adequate cultural standards into the new motion picture industry.

In his earliest cinema experiments he made use of photographs reduced microscopically on films. Thus he was familiar with the principle of the micro-film.

As he became older he depended more and more on assistants and obstinate work, and less and less on inspiration. In the last decade of the nineteenth century he made a tremendous effort to develop the method of concentrating iron ore by magnets. He believed that the exhaustion of deposits of rich ore would give the possessor of such a technique the monopoly of the world's steel industry. He spent most of his energy for eight years on this project. But the discovery of the very rich iron-ore deposits in the Missaba Mountains in Minnesota provided high-grade ore much cheaper than could be produced by magnetic concentration for low-grade material. Edison had to close down his plant, in which he had invested the whole of his life's savings of $2,000,000. In the future, when the deposits of rich iron-ore are definitely used up, interest in magnetic methods of iron-ore concentration may revive.

With characteristic energy and courage, he applied the wide experience he had gained in working minerals to the development of the Portland cement industry, carrying the process of continuous production of cement from rock to a more advanced degree than had been achieved before. In his forward-looking way, he made many experiments on the casting of houses in concrete. Here, again, he did not have great success, but his work was in the line of progress.

During the first decade of the twentieth century he devoted much of his time to the development of a new kind of electrical accumulator. The ordinary accumulator uses lead and sulphuric acid. It is heavy, not very robust, and the acid is corrosive and can be troublesome. His accumulator was made out of steel, and contained an alkaline electrolyte. It could be changed very quickly without danger, and was very robust. It has been much used in electrical traction and in submarines, but it has the serious limitation of giving a current at only about one-half the voltage of a lead accumulator.

Edison reached his sixtieth birthday in 1907. For the remaining twenty-four years of his long life he became more and more a national figure and symbol of America. His advice was sought incessantly, and generally it was below the quality of his genius. He was a man of action, and the best advice he could give was not in words, but in the example of his earlier life.

During the First World War he became president of the Naval Consulting Board of the United States for inventions. He stimulated a great deal of research especially on antisubmarine listening devices. He hung an apparatus in the water about twenty feet ahead of the vessel, which contained a phonograph diaphram. With it, the noise of torpedoes running in the water could be heard at a distance of 3,000 yards. When the torpedo was located, the ship was swiftly swung out of its track with the aid of a sea-anchor, consisting of a big canvas bag trailed in the water at the ends of long ropes.

Edison's board also worked on the location of gunpositions by sound-ranging, devices for smudging the skyline and submarine periscopes for evasive action; underwater searchlights, water-penetrating projectiles, field-glasses for use at night, and many other military inventive problems. But Edison himself did not have any very great personal success in this field.

Besides direct military inventions, he was much concerned during the First World War in the stimulation of the American chemical industry. Many of the raw materials for the manufacture of his own major inventions, such as phonograph records and electrical equipment, came from Germany and Europe. He needed potash for his storage batteries and was unable to obtain this in America. Accordingly he worked out the substitution of caustic soda for this purpose.

Large quantities of carbolic acid were needed for making phonograph records. Within a few months he had a plant producing six tons a day. Then he began producing benzol, toluol, xylol, and solvent naphtha, for the manufacturing of aniline dyes and explosives. His first benzol plant was put into commission within forty-five days of breaking the ground.

Another constituent required for phonograph records was the chemical paraphenylenediamine, which had previously been imported from Germany. Edison soon succeeded in making sufficient for his own needs. But paraphenylenediamine is also used by furriers for dyeing furs black. Without it, the American fur trade was in danger of being closed down. When the furriers heard that Edison was making it, they demanded supplies from him with desperate insistence, so he increased his output to meet their needs.

The most striking aspect of Edison's war-work was his speed of initiation of new production. In this he was a characteristic forerunner of the tremendous American achievements in speed of technical innovation and starting of new production in the Second World War.

Edison was always interested in the problem of conservation, both of human effort and of natural resources. His early invention of a simplified and streamlined method of handwriting sprang from this motive. His style of writing has since been followed by many of the most progressive educationists in teaching children to write. Each letter is written with the minimum of strokes and flourishes, more like print than cursive writing.

The same spirit of conservation stimulated him to try to develop machines for producing electricity directly from heat, without the interposition of the wasteful boiler and steam-engine. He constructed electric generators based on the effect discovered by William Gilbert in the time of Queen Elizabeth, that iron loses its magnetic properties when raised to a red heat. A pivoted iron bar was alternately heated and cooled. When cooled it was attracted by an adjacent electromagnet, and when hot the attraction disappeared. From the swinging of the bar backward and forward, rotary motion can be produced. This device illustrates Edison's ceaseless efforts to break into new fields.

His work on the measuring of smells is yet another example of his omnivorous interests. He devised an odoroscope consisting of a strip of gelatine the reactions of which to very small quantities of water vapour or perfume are recorded by a sensitive mirror galvanometer.

Other varied problems to which he addressed himself were the preserving of fruit in a vacuum, the making of plate-glass, wire-drawing, and the refining of nickel, gold, and copper. He introduced 'Hello' as the systematic call-word on telephones, a habit now officially deprecated by telephone services, and devised a machine for removing snow from the roads of New York, by compressing it into little chunks of ice which occupy only one-tenth of the volume and can easily be carried away.

His automatic 'nickelodeon' machines are one of the basic features of the fun-fairs which have multiplied in recent years. He devised a musical machine which operated one of Helmholtz's artificial larynxes, and sirens which gave articulate speech. Another invention arising from his investigations of sound was a method of concentrating sound-waves along a straight line, so that they did not spread, on a principle analogous to a smoke-ring.

Among his marine inventions were a galvanometer for continuously recording the depth of the ocean, and a method for the prevention of the fouling of ships by barnacles.

He invented an audiophone for assisting the deaf. An example of his work on new types of motive power is his engine driven by steam derived from the de-combination and re-combination of water with metallic salts, a type of chemical engine greatly developed by the Germans during the Second World War. He invented a method for combining odours, which might be used for producing a varying environment of perfumes, anticipating Aldous Huxley's speculations on 'smellies' in his *Brave New World*.

Edison's wealth of ideas and fertility of imagination were quite exceptional. In addition to their enormous range, they were always directed towards intensely practical ends, and very often foreshadowed main lines of developments which were extended by his successors.

He was even interested in the now fashionable subject of science fiction. He left an unfinished and unpublished novel based entirely on new inventions and devices as yet unknown to man.

He was prepared to try to invent a device of any kind of which he could see the practical value. This mechanical universality made him the classic type of the inventor who is engaged in mechanizing the whole of life, and substituting automata for performing all activities, both the important and the trivial. It is one of the aspects of his work which makes him a very significant modern figure, and the chief symbol of American inventiveness.

Edison was a man of medium height, with a very large head. His eyes were grey-blue, and in his childhood he was fair-haired. He had a good complexion and a lively step. In his thirties, he began to wear his hair with a sweeping lock over his forehead, like Napoleon. When he was interested in anything, his eyes had a very bright and penetrating look. They dominated his expression, which was otherwise rather spoilt by a surly twist of the mouth. He was known as *The Old Man* before he was thirty years old, and he had the power of employing and keeping very able men who disagreed with him.

As he had had a rough youth, with little formal education, and was also rather deaf, he spoke with an uncultivated accent, which he never bothered to modify.

M. A. Rosanoff, who was engaged by him in 1903, when Edison was fifty-six, has recorded his impressions of how he behaved at that time. After being taken on, Rosanoff asked what the laboratory rules were. Edison spat in the middle of the floor and shouted: 'Hell! there ain't no rules around here! We are tryin' to accomplish somep'n!' Edison introduced himself as 'Don Quixote', and his chief assistant J. F. Ott, who had been with him for thirty years, as 'Santcho Pantcho'; other colleagues were described as 'muckers'. He spoke of himself as the 'chief mucker'.

He was a shrewd judge of persons, and domineered over them by exploiting their weaknesses. He insisted on everybody being publicly cheerful, and hopeful about the outcome of his work, whatever his private thoughts might be. This produced a feeling of guilt in the victims, who worked harder than ever to justify themselves under Edison's relentless eye.

He was quite modern in his attitude towards publicity. His early excursions in journalism made him at home with the press. He used to say that 'we always tell the truth', and then added, 'it may be deferred truth'. In any case, ultimately, it was the whole 'truth'. He had no compunction in business competition. When the trade secret of his mixture for making phonograph records was stolen by a competitor, he betrayed no particular annoyance, unlike his assistant who had proved the theft by analysis of the rival's mixture. 'What are you so excited about?' he asked, and added: 'Everybody steals in commerce and industry. I've stolen a lot myself. But I knew *how* to steal. They don't know *how* to steal—that's all that's the matter with them.'

He was extremely pertinacious, and had an immense capacity for dealing with details. He started each day with an open and hopeful mind, like a child's, with all thoughts of failure dismissed from his consciousness. He could roar with laughter, and also had paroxysms of rage when he was crossed. On these terrifying occasions, the skin in the centre of his forehead used to rotate in spasms.

He was completely without taste in art, music, and literature. When the travellers of his phonograph company reported that the Germans demanded records of classical music, he was unable to believe it. The first phrase that had occurred to him to speak to his newly-created phonograph was 'Mary has a little lamb'. His mind naturally ran to fun-fairs for the use of his invention of motion pictures.

He often worked twenty hours a day for periods of months. There were other long periods, however, when he regularly slept nine hours every night at home in bed. He tried to drive his staff to work very long hours, but few of them could stand it.

When his son once complained of feeling tired, he recommended him to take a nap under a laboratory bench. The youth was retrieved from this position by his mother.

In his early days he did not bother about his food, but in his later years he dieted to keep his weight constant. He continued to smoke strong cigars, chew tobacco, drink strong coffee, and take no exercise.

He had a tremendous memory for miscellaneous facts.

His method of inventing consisted of putting these facts together empirically, with intense energy and persistence, until he had got what he wanted. He knew very little scientific theory.

In his first period, he did not care about his appearance. He was unkempt and dirty. Some of his staff used to daub themselves with grime as a kind of camouflage, which might make him think that they were working as hard as he was.

Edison domineered, but he was never solemn. He made inventions by direct assault on problems, and led his men, as Rosanoff put it, like a 'happy hooligan'.

He was granted more than one thousand patents. About two hundred of these were concerned with telegraphy and telephony. Several hundred were connected with the electric lamp and the central electric power station, and dozens covered various aspects of the carbon filament lamp. Scores of his patents were for his phonograph records. He had many for the alkaline accumulator, magnetic separation of iron ore and for cement manufacture.

Edison was very fond of talking of the necessity for subordinating invention to the demands of the market, and that time and energy should not be wasted on inventing things that were not wanted. He did not, however, accumulate a very large fortune. He received a lot of money, but he spent most of it on trying to accomplish more and more inventions. Rosanoff said that his real aim was to be a great man, to produce such a pile of brilliant inventions that he would astonish and permanently impress mankind.

Edison died at his home at West Orange, New Jersey, on 18 October 1931, at the advanced age of 84. He received the main recognitions of industrial life, and a number of academic honours, besides being celebrated by the whole American nation, and departed in an atmosphere of respectable benevolence which was in striking contrast with the fierce genius of his younger days.

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GUGLIELMO MARCONI

1874–1937

GUGLIELMO MARCONI was born on 25 April 1874 at Bologna, where, a century before, Galvani had discovered animal electricity and opened the path to the modern knowledge of electricity. His father Giuseppe Marconi was a well-to-do businessman, with a town house and a country estate. His mother, Giuseppe Marconi's second wife, was Irish. She was Anna Jameson, a daughter of Andrew Jameson, the well-known Irish whisky distiller. On her mother's side she was related to Lord Haig, the British commander-in-chief in the First World War. Anna Jameson went to Bologna to study music, and there met her future husband, whom she married in 1864. Her first son, Alfonso, was born in 1865, and her second, Guglielmo, nine years later.

Marconi was the younger son of rather old parents of considerable ability and different temperaments. His father was a shrewd and successful man of business. He took pride in remembering every detail of his transactions and pursuing it with solemn tenacity. He had a rather dry manner, and was fond of quiet and reading.

His mother's temperament was imaginative, cool, and determined. Guglielmo resembled her more than his father. He had wavy brown hair and blue eyes, like his mother, and there was a deep bond of imaginative understanding between them.

His brother Alfonso was an amiable boy, with excellent deportment and manners. He was a model child. Guglielmo was not. To some extent, perhaps, this was a reaction against his perfectly behaved elder brother. He was inclined to be mischievous, obstinate, and solitary. At the age of six or seven he appeared to be bright and intelligent, though no one suspected that he might be extraordinary. He was, on the whole, happy with his parents. His father was affectionate but strict, a man of executive character who believed that boys should be subject to discipline. His mother had a natural insight into his mind, and never found it necessary to scold him. He was in fact a mother's boy. She was the first to perceive his peculiar power of concentration, and strove persistently to help him to unfold his ability.

Marconi said that he had received most encouragement from his mother. His father was not much impresed until he had obtained recognized results. He spent most of his boyhood at the Villa Grifone, on his father's country estate at Pontecchio. This was a large, three-storied mansion on the side of a hill, containing many rooms, and a good library of scientific literature. It was surrounded by acres of grounds.

Guglielmo was retiring, but not shy. He did not like rough play with other boys. He preferred to climb trees by himself, and ride horses. He became passionately fond of fishing, and of the sea. He learned to sail a boat in the Bay of Leghorn at the age of nine. He said in later years that if he had been born poor, he would probably not have become an inventor but a sailor.

Marconi learned perfect English from his mother, and never lost a trace of English accent in his Italian. He used to tease the workers on the family estate by talking to his mother in English, so that they could not understand what was being said about them.

It has been thought that when he was a boy his English accent made him self-conscious, and that this may have caused him to withdraw from the neighbouring Italian boys' company, and have increased his solitary tendencies. He was fond of reading, and was given no regular schooling. A local grammar-school master was engaged to tutor him at home. Owing to his mother's delicate health the family went to Florence or Leghorn in the winter to escape the harsher Bologna climate. Private tutors were engaged there, too, so that his education should not be interrupted. Noticing his interest in electricity his mother engaged Professor Rosa at Leghorn to tutor him. He attended some lectures at the Leghorn Technical Institute, where he was specially interested in physical chemistry.

He fitted up a rude laboratory in a room on the third floor of the Villa Grifone, which his father had formerly used for storing silk cocoons bought from the local farmers for sale to manufacturers. He acquired primary batteries and thermopiles, and made experiments to try to convert heat directly into electricity. He experimented on the efficient use of steam in steam engines, and was deeply interested in chemistry.

He continued his amateur studies in science and electricity for several years, and then, about the time of his twentieth birthday, his attention was suddenly caught by the sad event of the premature death of Heinrich Hertz. In the spring of 1894, while in the Biellese Alps with his half-brother Luigi, he happened to read an account in an Italian electrical journal of the work of Hertz, who had died on January 1st of that year.

He had followed Hertz's researches for several years without special attention, but while reading this account the idea of wireless telegraphy suddenly occurred to him. He spent sleepless hours in his bed in the Alpine hotel, imagining how this might be carried out. Now and again he noticed the smell of the pine-trees, and a creaking board as someone moved about late in the night, and he afterwards associated these smells and sounds with his first ideas on wireless.

Hertz had produced a spark between the ends of a gap in a wire hoop, by means of electric waves which generated an oscillating current in the hoop. It occurred to Marconi that if the transmission of the waves could be interrupted, and broken up into longer or shorter periods, then the spark in the gap of the receiving hoop would also appear for longer or shorter periods. The spark which appeared for a shorter period might correspond to a Morse dot, and the spark for a longer period to a Morse dash.

When he first had the idea he did not have any thought of carrying it out in practice, for it seemed so simple and obvious. He knew that many able men had been experimenting with the waves and he naturally assumed that it would have been one of the first things which they would have done.

He expected to hear at any moment the announcement that it had been done, and spent the summer dreaming in the Alps of ways of doing it. He continued to wait for several months but he heard no such announcement, so he returned to the Villa Grifone in the autumn determined and prepared to make experiments of his own.

His mother set aside two large rooms on the third floor for his use. He rose early and worked late, keeping the rooms locked, and not telling his father what he was doing. He was scarcely seen by the family, and his father used to remark that it would be fine to see something of one's son occasionally.

Guglielmo was too sensitive to adverse criticism, and shrank from mockery and lack of sympathy. His taste for fishing was probably developed in order to escape from other people, avoid conversation, and think by himself alone. He never became a very expert fisherman.

In spite of the cold weather, his mother stayed with him through the winter at the Villa Grifone. She occasionally came to his rooms to see how he was getting on; sometimes a maid accompanied her with a tray of food for him, for he was often oblivious of meal-times.

THOMAS ALVA EDISON

Aged about 31

By courtesy of Picture Post Library

GUGLIELMO MARCONI

Aged 22

He began his experiments in December 1894, and immediately obtained surprising results, which appeared to him to be new. Presently, a moment came when he went down from his rooms and woke his mother up in the middle of the night, to bring her to see his first success. He had succeeded in making an electric bell ring by electric waves, over a distance of thirty feet.

His father was not impressed, and suggested that after all there were various ways of making a bell ring.

Before the end of the year, Marconi had sent the first recorded message through space by electromagnetic waves.

He began experiments in the grounds of the villa in the spring of 1895. His father did not much like all the disturbances in his beautiful garden, with its magnificent avenue of chestnut trees. He objected to the poles being stuck up in various places, and holes being dug in the ground. Guglielmo therefore worked mainly in the early morning or late at night, so as to be as inconspicuous as possible. These unusual hours appealed to his romantic imagination, and his first experiments in the open became associated with the scent of the newly-dug earth, and morning dew.

He mobilized his brothers and the sons of the estate workers to help him with the experiments, carrying apparatus about, and co-operating in observations. In spite of his solitariness, he was a leader. Undoubtedly, he had something of the habit of command as the son of a rich landowner on the family estate, in addition to a natural capacity for imposing his will on others.

This, then, was the situation of Marconi in the middle months of 1895. It is necessary now to glance at the stage which the scientists had reached at that time in their researches on electric waves.

The effects of electric waves had been noticed long before their existence had been dreamt of. The earliest recorded instance was in 1780, when Adams noted that tiny sparks passed between conductors near to each other at the moment of the discharge of a Leyden jar. Galvani himself published an observation of a similar kind in Marconi's own birthplace in 1791.

In 1842 Joseph Henry used a magnetic detector for registering the occurrence of distant lightning flashes, and he noticed that the spark discharge of a Leyden jar affected such a detector in a basement thirty feet below his laboratory. Another remarkable instance occurred in 1879, when D. E. Hughes, the musician who invented the electric printing telegraph and the carbon microphone, discovered that a tube loosely packed with metal particles was sensitive to a spark at a distance. In 1880 he demonstrated the phenomenon to Spottiswood (then president of the Royal Society), Stokes, and Huxley. Stokes said that it was due to induction and not to conduction and 'rather pooh-poohed all results from that morning'. Hughes recorded that after they had spent two and a half hours with him, they 'left very coldly'. Hughes took a telephone receiver out into Great Portland Street and heard the clicks in it up to a distance of 500 yards from the spark. Thus, in 1880, Stokes virtually throttled the experimental discovery of electric waves.

Edison, Elihu Thomson and others had also noticed sparks which were probably due to electric waves. The first conception of electric waves was due to Faraday. He deposited a sealed letter in the Royal Society in 1832, which was not to be opened for a long time. In 1937, it was decided to open it, and Sir William Bragg, who was then the president, found that it contained a statement that Faraday could not but think that the action of electricity and magnetism is propagated through space in some form of vibration.

In 1846, Faraday expounded this idea in a lecture at the Royal Institution, and in 1865, James Clerk Maxwell showed that the mathematical description of Faraday's experimental discoveries in electromagnetism led to the deduction that electrical action must be transmitted by waves with the speed of light.

It is remarkable that the existence of these electric waves remained undemonstrated for twenty-two years. Then, in 1887, Heinrich Hertz, a young research worker who had been told by Helmholtz to try to find them, had à brilliant success. He produced electric waves of known wavelength, and demonstrated the phenomena of reflection, refraction, and interference with them, exactly analagous to those which can be obtained with visible light. Hertz's discovery aroused the intensest interest. Physicists in many countries repeated his experiments. Hertz's aim, and that of the other physicists, was to extend the knowledge of this new range of waves, as part of the fundamental exploration of nature. He especially worked in this spirit, for he had started life as an engineer and had changed over to science because he preferred fundamental research.

Among his earliest followers were Professor A. Righi at Bologna, and Professor Oliver Lodge in England. Righi had a house near the Villa Grifone, and Guglielmo Marconi knew him. He had had discussions with him on chemistry and mechanics, but he did not receive his first knowledge of electric waves from him. Marconi said that he had never attended any of Righi's lectures on these waves, though he wished that he had. When he first mentioned the idea of wireless to him, Righi thought that it would not be practicable. Righi increased the violence of the spark by filling the space between the discharge knobs with vaseline instead of air. In this way he increased the strength of the waves produced by the spark. Marconi utilized Righi's device to increase the range of his transmitter.

In England Lodge introduced the use of the coherer. The influence of electric discharges on powders had been noticed as early as 1850 by Guitard, who had observed that the particles of dust seen dancing in sunbeams tended to coalesce when an electric machine was worked nearby. Many others noticed similar effects, and then in 1891 Branly showed that metal filings in a tube tended to cohere when an electric discharge occurred in the vicinity. The filings could be loosened again by tapping the tube. Lodge adapted the coherer for detecting the electric waves, and in 1894 devised a mechanical tapper which automatically de-cohered the filings after the waves had been received, and so made the receiver ready to receive the next signal.

In April 1895, Professor A. S. Popoff described to the Physio-Chemical Society of St. Petersburg his use of a high vertical aerial and earth connection for receiving electric waves from distant lightning discharges. The oscillations produced in the aerial by the incoming waves were detected by a coherer furnished with a tapper. In December 1895 Popoff predicted that if a sufficiently powerful transmitter of electric waves could be devised, his apparatus might be adapted to receive wireless signals. He published an account of his experiments in *Elektritchestvo* in July 1896.

In 1892 Sir William Crookes published a remarkable article in the *Fortnightly Review* on the possibilities of wireless communication, after listening to one of Lodge's lectures on the new waves. Crookes commented on the almost infinite range of the waves, with wavelengths from thousands of miles down to a few feet. An astonishing new world had been unfolded, and it was difficult 'to conceive that it should contain no possibilities of transmitting intelligence'. It 'revealed the bewildering possibility of telegraphy without wires'. It was possible to focus a sheaf of the rays in a desired direction, and messages in the Morse code could be signalled from one operator to another. Any two friends could arrange for their respective instruments to be 'attuned', and receivers could be designed to operate on a particular range of wavelength, and be silent on others. He assumed that instruments would be adjusted to receive a particular wavelength by turning a screw. This would give 'sufficient secrecy', and this could be increased by using a code. All this was 'no mere dream of a visionary philosopher'. The means for bringing it into daily life were well within the possibilities of discovery, and were so reasonable, and so clearly in the line of researches 'being actively prosecuted in every capital of Europe', that the announcement that they had 'emerged from realms of speculation into those of sober fact' was to be expected at any moment.

At the British Association meeting at Oxford in September 1894, Lodge demonstrated the possibility of Morse signalling by wireless. On the suggestion of the telegraphist Muirhead, he sent dot and dash signals over a distance of 180 feet through two stone walls. He used a Kelvin dead-beat mirror galvanometer to make long and short sweeps of a beam of light on a scale. He had an automatic Morse inker on the table, but did not bother to connect it in the circuit.

Lodge did not publish an account of this demonstration. Even after Crookes' article of two years before, inspired by his own work, Lodge still did not see the practical implications of his experiments. In 1923 Lodge said that he had been too busy with teaching to take up any development, nor had he 'the foresight to perceive what has turned out to be its extraordinary importance', especially for ships and in war. In his *Autobiography* Lodge wrote that after he had demonstrated the detection of electric waves by means of the coherer, the great Lord Rayleigh said to him: 'Well, now you can go ahead: there is your life work!' But he didn't. He was engaged in teaching and 'neglected the prelude to what has now developed into wireless telegraphy'.

In 1894 a young research student in New Zealand rediscovered the magnetic detector for himself, and early in 1895 demonstrated the transmission of electric waves over a distance of 60 feet. This was Ernest Rutherford. After he came to Cambridge in 1895 Rutherford improved his detector and increased its range to half a mile. J. J. Thomson inquired in the City of London about the possibility of commercial support for the development of Rutherford's radio work, and was told that wireless communication was not likely to be of any practical use. Rutherford himself formed the opinion that his magnetic detector was less sensitive than the coherer. So for various reasons he suddenly dropped the electric waves and turned to assist J. J. Thomson to discover the electron, and pursue that path which ultimately led him to the nucleus of the atom.

Six years later, Marconi improved Rutherford's magnetic detector and used it to supersede the coherer. His opinion on the technical prospects was exactly the contrary of Rutherford's, and is a striking illustration of the difference between their respective geniuses. Marconi made the magnetic detector the standard instrument for his system for the next ten years.

The solitary youth in the grounds of the Villa Grifone was quite outside the stream of pure research which flowed in the first few years from Hertz's discovery. He was in one way even more isolated than Rutherford in New Zealand, for he was not a member of an academic institution. There were no colleagues with whom problems could be discussed.

His attitude towards the new waves was quite different from that of the professional scientists. They knew that the waves might become a means of communication, but that was not their primary interest. They were concerned with the waves as a vast hitherto unknown region of natural phenomena, which they hastened to explore.

Marconi was from the first seized entirely by the practical idea. How could the new waves be used for telegraphy? He was interested in them not for themselves, but as a means to an end. Always, from the beginning of his career to the end of his life, he had one interest: the development of a practical system of wireless communication, and in particular the communication of information. He always felt that Morse wireless telegraphy, which could transmit the information of business, war, and politics was more important than wireless telephony. For him, sound broadcasting was never as fundamentally important as wireless telegraphy.

Marconi was an inventor rather than a scientist, and his inventions arose in the first place out of the utilization of the scientific discoveries of others. Working by himself, he concentrated entirely on his own aim, the invention of a practicable system of wireless telegraphy. For this he needed especially two things, the ability to transmit over great distances, and simple, reliable, fool-proof equipment. When he looked at the scientists' laboratory apparatus he at once saw its innumerable limitations from his point of view. The *recognition of these limitations led him almost immediately* to invent improvements which removed them.

He at once increased the range by adopting Righi's more energetic form of oscillator, with discharge knobs in vaseline instead of air. Then he made the range far greater still by connecting one pair of spark balls to a long vertical wire or high aerial, and the other to the earth. This greatly increased the electrical capacity of the transmitter, and hence its radiating power.

Besides increasing the power of the transmitter, Marconi increased the sensitivity of the receiver. He greatly improved the coherer, and connected it with a sensitive telegraphic relay to operate a Morse printer.

By transferring his apparatus from the house into the garden, he unconsciously took it out of the laboratory environment into the exposed conditions of the open air. Experiments in the open at once increased his sense of distances to be overcome, and of the need for robust apparatus to withstand the weather. This helped him to devise the sort of apparatus which could subsequently be adapted to use on ships at sea.

Presently he took his receiver outside the grounds and found that it would pick up messages even when it was on the other side of a hill. This experience gave him an unshakable confidence that wireless waves could surmount any obstacles on the surface of the earth.

Marconi did all this by himself in the Villa Grifone by about the end of 1895. Not having received any regular scientific or technical instruction, he had only a small knowledge of mathematics, was an indifferent draughtsman, and a rough-and-ready engineer. Many of the most gifted physicists in the world had been working with electric waves for eight years, but it was not from within their ranks that the inventor of practical wireless telegraphy came. The young Italian amateur of twenty overtook them all. It was a magnificent demonstration of his originality and greatness. Though, as Crookes had said, scientists in every capital in Europe were studying the waves, Marconi was able to claim that he 'sent the first recorded message through space by electromagnetic waves in 1894'. He said that he had made use of known ideas, that his instruments were improvements of his predecessors', and that he had introduced a few developments arising out of his own observations. 'It is only fair to say that the introduction of these new elements was the basis of my long-distance success.' It was the business of science, in his opinion, to acquire results with the least possible outlay of work and time, and 'results are regarded as the standards by which a man's work is judged'.

His mother had prevailed upon his father to give him one thousand lire for the prosecution of his experiments. When the results had become definite, his father gave him warm support. Meanwhile, his mother wrote long letters about her extraordinary son and his work to her relatives in Ireland, who had important commercial and social connections.

Owing to her efforts, interest was aroused in English political and commercial circles in her son's experiments.

The significance of wireless telegraphy in war at sea had been immediately recognized by experts in the British Admiralty, and secret research on it had been pursued since 1891 by Captain H. Jackson. By 1895, independently of Marconi, Jackson had signalled in Morse code over a few hundred yards by wireless. These experiments were, of course, unpublished. But there were persons about who were very much alive to the possibilities. During the First World War, Jackson became the First Sea Lord of the Admiralty, and was in charge of the Navy during the decisive naval action of the war, the Battle of Jutland. The surmise that the German fleet had left harbour arose from the observation of the direction from which German naval wireless signals were coming.

As a result of his mother's activities, Marconi came to London, accompanied by her, in February 1896. Her relative, Jameson Davis, who subsequently founded the Marconi Company in England, arranged for them to stay in a quiet boarding-house in Westbourne Park where Marconi could test his apparatus. Mother and son arrived with numerous packing-cases, bags, and sacks.

He was soon put in touch with William Preece, the chief engineer of the Post Office, a very able and sympathetic man. Preece arranged for him to set up his transmitter on the roof of the General Post Office in London. Morse messages were successfully transmitted to receivers on the Thames Embankment several hundred yards away.

Marconi applied for his first patent in June 1896, covering the use of a transmitter with coherer connected to a high aerial and earth. This was the first of all wireless patents.

Preece, under Government instructions, assisted Marconi with all the engineering resources of the Post Office to test his apparatus and ideas. Wireless signalling was conducted over the Bristol Channel between Penarth and Weston-super-Mare. Then transmissions up to nine miles were demonstrated on Salisbury Plain, before high naval and military officers. He used parabolic reflectors some two feet in diameter for focusing short waves, of about half a metre wavelength, in the direction of the receiver. He accomplished transmissions of two miles on these beams of short waves.

The use of such reflectors, known as 'cheeses' was revived in the Second World War for scanning with short wave radar, especially for the detection of the periscopes of submarines.

Preece gave most enthusiastic lectures on the new wireless, and at some of these Marconi attended and answered questions. Audiences were astonished at the youthful appearance of the twenty-two-year-old Italian inventor. He was always smartly dressed, spoke English perfectly in a low, soft voice, and had an intense reserve which seemed far more English than Italian. Everyone thought he was an Englishman until they learned that he was not.

He did not like general conversation, and much preferred to make demonstrations and leave these to speak for themselves rather than talk about them.

Owing to his well-to-do upbringing and his natural reserve, he did not feel obliged to ingratiate himself with persons of wealth and power. He took it for granted that he was one of them, and regarded wireless telegraphy as his own property. His cool and cautious attitude was not only temperamental; he aimed *from the first at a monopoly of wireless*. He followed his first patent, the first in wireless, with every possible patent of each conceivable improvement. He tried to establish an impregnable defensive position around his wireless, and part of his technique was to be very careful what he said, never dropping an unconsidered word which might be used against him in the industrial struggle for power. His whole life and career became a kind of prospectus for his invention.

His youthful brilliance, which was so striking against the background of mature and elderly scientists, secured for him an immediate popular sympathy. But this was soon dissipated by his manner and attitude. In spite of the public admiration in his favour, he was not a great social success.

Nevertheless, while basing his fundamental position on an array of patents, the suppression of competitors by exercise of patent rights, and practical improvement of his system as an instrument of commerce and war, he paid great attention to publicity. He was continually being received by Royalty and fêted by societies. He gave frequent interviews and press conferences, though few prominent men have been less at ease than he in them.

Owing especially to his mother's connections, Marconi had less than the usual difficulty in finding financial support for the development and exploitation of his inventions. The first wireless company, Wireless Telegraph and Signal Company Ltd. was founded in 1897, with Jameson Davis as managing director. The membership of the board was exceptionally distinguished, and a large part of the capital of £100,000 was guaranteed by a few wealthy investors. The company bought most of Marconi's patents, for which he was paid £15,000, and he was given 60 per cent of the stock. Its name was changed to Marconi's Wireless Telegraph Co. Ltd. in 1900.

One of Marconi's acts when he first received some money for his inventions was to buy a bicycle, not an expensive model, but one which best suited his practical needs.

Though Marconi was young, he sought the very best advice and assistance which he could secure. He was only in the middle twenties, but he had the nerve to commission technical advice from Lord Kelvin, who was then nearly seventy years old, and had for thirty years been the head of

British physics. In 1899, when he was twenty-five, he engaged the eminent electrical engineer J. A. Fleming, who subsequently invented the radio valve, and was then fifty years old. Besides such men as these, he engaged very able young men, such as C. S. Franklin, who subsequently developed short-wave beam radio communication. These men were far superior to Marconi as physicists or electrical engineers, but in his field of wireless invention he surpassed them just as much as they surpassed him in theirs.

By 1900 he already had a scientific staff of seventeen. Evidently, he had great strength of personality to control the services of such men. He was not afraid of employing those who were much abler than himself in their own special fields, and he could control them without the assistance of personal popularity.

When his staff grew to 700, probably not more than half a dozen of them knew him well enough to speak to him. All of his interests were subordinated to his one over-mastering idea of wireless telegraphy. He would work for sixteen hours a day for days together, and sometimes for thirty hours at a stretch, to solve some urgently required practical improvement. He did not like business routine and administration, but he had a sharp sense of their main principles, and in spite of his reserve he had a natural insight into the ways of the world.

Marconi was confident from the beginning that his system would ultimately compete commercially with the existing telegraph and cable system. He arranged that Lord Kelvin should send the first wireless telegram. Kelvin chose, probably quite unconsciously, for they were great friends, to send it to Sir George Stokes, who years before had discouraged Hughes in his experiments.

Marconi reported the progress of the races of the Kingstown yachting regatta for the *Dublin Express*, and James Gordon Bennett invited him to America to report the

America Cup yacht races for his *New York Herald.* He was invited by Queen Victoria to establish wireless communication between the Royal Yacht *Osborne,* off the Isle of Wight, to Osborne House. The Prince of Wales was nursing an injured knee on the yacht, and Her Majesty desired frequent reports on its condition. One hundred and fifty messages were exchanged by wireless in sixteen days.

Marconi remarked that the greatest astonishment seemed to be caused among the non-expert by the possibility of signalling by wireless from a ship while it was in motion.

These demonstrations were primarily performed in order to draw public attention to the practical possibilities of wireless communication at sea. Marconi incessantly strove to provide the press with news-stories.

Meanwhile, he worked on the improvement of his apparatus and the extension of his monopoly. In 1897 Oliver Lodge had patented the fundamental method of tuning transmitters and receivers of electric waves. Marconi worked out the application of this principle of tuning to practical wireless transmitters and receivers, and filed a patent for this innovation in 1900. This was the famous Patent 7777. For eleven years he defended it successfully in the British courts. But in 1911 Lord Moulton ruled that Lodge's patent was the master. The Marconi Company thereupon bought Lodge's patent from the Lodge-Muirhead Syndicate, which had been formed in 1901 with a capital of £50,000 to exploit this patent. The Syndicate had never been able to secure a commercial licence to operate in Britain, and had not been a financial success. It was dissolved after the sale to the Marconi Company, and Sir Oliver Lodge thereupon received from the Company a substantial income.

As part of his tenacious policy of control, Marconi had decided in 1900 not to sell his equipment to users, but only to lease it. When Fleming invented the diode, the first form of radio valve, about 1904, he asked Marconi to allow it to be manufactured for sale, but Marconi replied that his valve was likely to become a very valuable receiver for long distance wireless, and 'I wish if possible to keep the monopoly of these experiments to ourselves'.

Under the terms of Fleming's contract, his radio inventions became the property of the Company. He was not, therefore, able to decide how his own valve should be exploited. Marconi's view was that he was entitled to a monopoly, in order to secure the income for the research and development which was necessary for the perfection of wireless, which he was determined to carry out himself, or under his direction.

In these early years, Marconi appeared as a rather overneatly dressed young man with sad keen eyes, and tight thin lips. His hair was carefully brushed, and he often shaved twice a day. He usually wore a fur coat out of doors. He prided himself on punctuality, and would not see, or was very cool to, those who arrived late for interviews. His manner was ever in complete contrast to that of the unfashionably dressed absent-minded professor. Marconi moved in the high society of the Edwardian period, and would not have felt himself out of place in the world of Oscar Wilde.

He had very little to do with the majority of his colleagues, and disliked being recognized in his own institution. He had a difficult temper, but always had it under control. He co-operated well with the very small group of his immediate assistants. Consequently, he appeared equable; but he did not suffer fools gladly.

The fundamental requirement for a wireless system which could compete with telegraph wires and cables was immediately pursued with the utmost intensity. This was distance of transmission, and especially transatlantic communication. The great potential market was for wireless messages between the continents of Europe and America.

When Marconi had established reliable wireless telegraphy over distances of 170 miles at sea, he felt that this was a sufficient negotiation of the bend of the earth to hazard the attempt to send electric waves over the enormous hump of the Atlantic between the two continents. He decided to try to extend his range from 170 miles to more than 2000 miles in one jump. It was a breathtaking decision, and his subsequent success was one of the greatest achievements in the history of invention.

When Marconi decided to make the attempt he was only about twenty-six. He ordered the construction of a powerful transmitting station at Poldhu in Cornwall, and a receiving station at Cape Cod in Newfoundland.

Marconi asked Fleming, who had had experience of the design of high-tension electrical machinery for electric lighting supply, to design the transmitter, which was to be of a higher order of power than any seen before. Fleming guessed that it would have to be of about 25 horse-power, and designed it accordingly.

When the two stations were ready, Marconi sailed for Cape Cod, in November 1901. Owing to the wild Canadian winter weather, they were unable to erect very high masts at the receiving station, so they suspended a long aerial from a kite flying at 400 feet, at a site called Signal Bay.

When all the receiving instruments had been adjusted to the maximum sensitivity, Marconi and his assistants, G. S. Kemp and P. W. Paget, began to listen for a pre-arranged signal from Poldhu. This was the letter S, which is represented by three successive dots in the Morse code. The signal was transmitted continuously from 3 p.m. to 6 p.m. every afternoon.

As no meter for measuring wavelengths had yet been invented, the exact length of the Poldhu wave was not known, so the wave had to be hunted for by the tuning instruments at Signal Bay. Marconi, whose hearing had become highly trained by years of intensive listening, presently detected the three clicks of the Morse letter S. He had his observation carefully confirmed by Kemp, but Paget, who was slightly deaf, was unable to hear them.

Marconi had succeeded in hearing Poldhu in the daytime. He had not yet discovered that long waves travel much more easily at night. If he had listened while both Signal Bay and Poldhu were in darkness the clicks would have been much louder.

Marconi's announcement of his success caused a tremendous sensation. The press, which he had carefully cultivated, celebrated the apparently magical achievement with wild enthusiasm. Fleming read the announcement in *The Times*, and was surprised to find no reference to his part in the work.

The scientific and technical world received it with caution and scepticism. The theoretical physicists said that the electric waves could not have bent so far round the surface of the ocean. Edison remarked that one was always liable to hear stray effects which might be mistaken for the prearranged signals. Lord Rayleigh said that the waves could not have crossed the Atlantic by wave diffraction, and questioned the authenticity of Marconi's observations.

In short, Marconi had virtually the whole of the scientific and technical world against him. The theorists vigorously re-investigated the whole problem, and Rayleigh, Poincaré, J. W. Nicholson, A. E. H. Love, March, Rybzynski and G. M. Watson proved conclusively that it could not be due to diffraction, the kind of phenomenon that enables waves to get round corners to some extent.

Then Oliver Heaviside and A. E. Kennelly suggested that the bending of the electric waves was due to the ionization of the upper atmosphere by the light from the sun. This made the upper air a conductor, so that it was able to reflect or refract the electric waves. Later research established the correctness of this conception.

In his stretching out to create the basis for an intercontinental system of wireless communication, Marconi had made a major discovery in geophysics, the physics of the earth. His magnificent experiment, carried out in face of an almost universal scepticism, had revealed the existence of a whole new region of hitherto unknown phenomena in the upper atmosphere. Evidently, many things were happening up there which had previously been undreamt of, and long years of research into their nature began.

It soon became evident that the properties of the ionosphere were very complicated. Research on it was conducted from two points of view. Marconi investigated it in order to discover how wireless transmission could be improved, while geophysicists used wireless waves to explore it in order to discover what a new and unknown region of the globe was like.

While Marconi's achievement of transatlantic transmission justly raised him into the ranks of the major inventor-scientists of all time, the very thing that raised his reputation also nearly ruined him commercially. The unsuspected ionosphere proved to be subtle and fickle. Sometimes it would bend the electric waves round the Atlantic, but sometimes it would not. It was a wonderful new object for research, but it was a most awkward means of transport for electric waves carrying the messages of commerce. Sometimes, the waves were liable to fade out altogether, and at others they were drowned by disturbing atmospherics.

A system of wireless communication which sometimes worked and often did not was of no use in competition with the highly reliable submarine cable, which was not upset by storms or subject to unpredictable interferences. Though he had succeeded in sending a wireless signal across the Atlantic in 1901, Marconi found that no less than seven years of intense labour were necessary before a commercial system of wireless between the continents could be established, in 1908.

The financial position of his company became very difficult. The great experiment of 1901 had cost £40,000. It had brought great prestige, but no income. On the commercial side, his company had to concentrate on the Marconi wireless system for ships. Its importance for safety at sea was obvious, and many of the larger British ships were supplied, at appropriate fees and rates, with a Marconi service of operators and instruments.

Meanwhile, Marconi spent a great deal of time at sea, making observations on wireless waves, to find the solutions to the problems of inter-continental transmission, and the means for successful competition with the cables.

In 1902 he first noticed that long waves were transmitted better at night than during the daytime. Observations on the S.S. *Philadelphia* showed that there was no difference between day and night signals up to five hundred miles, but beyond seven hundred miles day signals faded out, while at night similar signals might be heard at over two thousand miles.

These observations led to the recognition that transmission occurs by two waves, one along the surface of the earth, and the other which goes up into the sky and is reflected down.

In 1905 Marconi discovered the directive properties of aerials. He found that a horizontal aerial parallel to the earth's surface radiated most strongly in the direction opposite to the free end. He utilized this property for locating the position of ships, and located a ship by this means at a distance of sixteen miles with high accuracy. The theory of this directive aerial was not worked out until the following year, when Fleming gave the explanation of its properties. Marconi had discovered it by insight and experiment. He had a power of compelling Nature to reveal her secrets. When he had an inkling of a possibility, he pursued it with prodigious determination and perseverance.

Long-distance transmission could be accomplished much better by continuous wave transmitters, as resonance effects could be employed to produce a singing note. Operators could distinguish this much more easily than the clicks from spark transmitters, from the background of disturbing noise caused by atmospherics. Marconi had started with spark transmitters, and the patents for continuous waves were held by other syndicates. He met this very difficult situation by developing a mechanical method, called the 'time disc' system, by which a semi-continuous wave could be produced. It was the product of enormous labour, and was a technical success. It enabled an unlimited commercial wireless telegraph service to be inaugurated across the Atlantic for the first time in 1908. The time-disc machines were very noisy and disturbing to the operators in the transmitting stations, who presently nicknamed them 'rock-crushers'.

Marconi received a well-deserved Nobel Prize for physics in 1909. He mentioned in his Nobel address his observation that low-power ships' wireless signals could sometimes be heard at distances of 1,200 miles. He had observed a difference in wireless transmissions between North and South, and East and West. Near sunrise or sunset a short wave was received better than a long wave across the Atlantic. These were important new observations which were contributions both to the science of wireless, and the physics of the atmosphere.

Marconi married for the first time in 1905. His wife was the Hon. Beatrice O'Brien, a daughter of Lord Inchiquin. Though he had three children, this marriage did not prove permanent, and was dissolved in 1927.

Apart from his personal affairs, Marconi's connection with the O'Briens had very important consequences for his company. The Marconi Company was founded in 1897, but paid no dividends until 1910. Marconi was both business and technical managing director, and he battled simultaneously with an iron will against his commercial rivals and with the technical problems of wireless development which had proved to be far more complicated and difficult than had been foreseen.

In this struggle, it was not surprising that he was finding difficulties on every side. He had come into collision with nearly everyone, even including Sir William Preece, who had done so much for him in his first days in England. Preece told a Select Committee of the House of Commons in 1907 that he had formed the opinion that the Marconi Company was the worst-managed that he had ever had anything to do with. Its character was chiefly indicated by the fact that it quarrelled with everybody.

Marconi was primarily interested in the technical side. He stated in 1912 that his company had spent £360,000 and engaged 200 engineers, 'on many long years of hard work and experiment', to develop long-distance wireless communication. He was personally rich, and was not dependent on the fortunes of his company. On one occasion, in 1910, he lent it £12,000, when it had run out of cash, to pay immediate running expenses.

While the strategic importance of wireless to the British Navy and imperial interests would probably have caused the company to be preserved, it became evident that it would probably never be a commercial success until the business management was altered.

Marconi began to look for a man who could relieve him of the business side, and in 1909 his brother-in-law, the Hon. D. O'Brien, introduced him to Mr. Godfrey Isaacs, who had impressed him in business dealings. It was presently arranged that Mr. Isaacs should become joint managing director of the company with Marconi, in the first place for a test period of six months. Mr. Godfrey Isaacs entered into this appointment in January 1910.

In March of that year, one of the company's engineers drew Mr. Godfrey Isaacs' attention to a proposal that the company should secure a contract from the Government to erect an Imperial chain of wireless stations. The German Telefunken system was attempting on its part to establish a world-chain of stations.

The Company wrote in March to the Colonial Office asking for twenty-years' licences to erect stations throughout the Empire. No answer was received until November, when the company was informed that the proposal would require consideration at the Imperial Conference at the time of the Coronation of George V.

It was in the same month of March, 1910, that Mr. Godfrey Isaacs' brother Rufus was promoted from among the private members in the House of Commons to be the Solicitor-General. In the following October he became Attorney-General.

In June 1911 a sub-committee of the Committee of Imperial Defence approved a suggestion that the erection of six stations, to be owned by the Government, should be put in hand at once, and negotiations with the company for terms should be undertaken.

The recommendations of the Government committees for the erection of stations came to the Postmaster-General, Mr. Herbert Samuel, to carry them out. After leisurely negotiations the Post Office and the company found themselves in accord, and the company submitted a tender in February 1912, which was provisionally accepted in writing by the Post Office on 7 March 1912. Godfrey Isaacs informed his brother Sir Rufus casually some days before this, that such an agreement was in contemplation.

On March 9th Marconi and Godfrey Isaacs sailed for New York to deal with the difficulties of the American Marconi Company. They arrived on March 16th and were entertained at a big public banquet organized by the *New York Times*. The newspaper had previously obtained a telegram of a few words from Sir Rufus Isaacs, containing the sentence: 'Please congratulate Marconi and my brother on the successful development of a marvellous enterprise . . .', which was read out, with many similar communications, at the banquet.

In 1910 the American Marconi Company had an accumulated deficit of $445,102. This was written off in 1911 and 1912, and in the spring of the latter year its shares were still at a discount. It was engaged in litigation against the United Wireless Company of America. The latter company, however, which had most of the wireless business of America went into liquidation, so Godfrey Isaacs proposed that the capital of the American Marconi Company should be increased by several million dollars to buy its assets, and engage in other developments. The American Marconi directors refused to agree to the increase unless Marconi and Godfrey Isaacs were willing to undertake the financial responsibility on behalf of the English Marconi Company. Marconi only agreed to this on condition that Godfrey Isaacs personally took 500,000 of the new American Marconi shares. The latter distributed most of these among various financial agents.

On 9 April, 1912, Godfrey had lunch with his brothers Sir Rufus and Mr. Harry Isaacs, and offered them some of his remaining shares. He assured Sir Rufus that the relations between the English and American companies were such that the American company could not receive any advantage if a contract were placed by the British Government with the English Marconi Company. Sir Rufus, after consideration, declined the offer. But after he had departed, Mr. Harry Isaacs agreed to take 50,000.

A few days after April 9th, the American Marconi shares began to rise. As for the English Marconi Company, its shares rose spectacularly from about fifteen shillings, until, by April 16th, they touched nearly ten pounds each.

On 14 April 1912 the world had been shocked by the sinking of the biggest ship, the *Titanic*, on her maiden voyage. The vessel was supposed to be unsinkable because of her special construction, and in this belief the captain had driven her by a field of ice at full speed. She struck an iceberg just before midnight, and sank within three hours. As many as possible of her passengers and crew were launched in life-boats, and continuous wireless calls were sent out by the two Marconi wireless operators, who stayed at their posts to the end, and went down with the ship. Owing to the wireless signals vessels in the vicinity steamed to the scene of the disaster with all speed. Seven hundred and twelve survivors were rescued, and 1,517 persons were lost.

Marconi wireless not only played a large part in enabling the survivors to be saved, but also kept the world instantaneously informed of the sequence of events. It was learned that a ship very near to the scene of the disaster never heard of it, because it had no wireless equipment. If it had had wireless, it would doubtless have saved many more of the lost.

World public opinion now demanded that wireless equipment should be made compulsory for all ocean-going ships. Naturally, these demands gave an additional stimulus to the shares of the Marconi companies.

On the evening of 17 April 1912 Harry Isaacs called on Sir Rufus and pressed him to take some of his American Marconi shares, and Sir Rufus finally agreed to take ten thousand at two pounds each.

Later in the evening of April 17th Sir Rufus offered some of the shares he had acquired to Mr. Lloyd George, who was then the Chancellor of the Exchequer, and to the Master of Elibank, who was living at the time in the Chancellor's house in Downing Street. He was then Patronage Secretary to the Treasury and Chief Government Whip. Both accepted the offer. Sir Rufus said that they need not bother to pay at the moment, as the shares were not yet actually in existence.

The issuing of the shares was authorized by the American shareholders on April 18th. On the night of this day they rose to 3 on the London market, and fluctuated between 3 and 4 on April 19th. Shares that had been worth about £1,000,000 in July 1911 rose to about £4,000,000 in 1912. As Sir Rufus Isaacs and Mr. Lloyd George had bought the shares in their own names, the fact that Ministers were investing in Marconis soon got around in the City. Most of the persons who heard it assumed they were investing in English Marconi shares, and doubtless this rumour contributed to their rise.

Sir Rufus sold 7,000 of his shares on April 19th at about 3½. By March 1913 he had incurred a loss of £1,300 on the whole transaction.

The English Marconi Company's negotiations for a contract for a chain of stations continued during the first half of 1912. During the early months of the year rumours spread in the City and in the clubs that Ministers were financially interested in the successful conclusion of the contract. It was alleged that the Attorney-General had been instigated by his brother Godfrey to use his influence with the Postmaster-General, Mr. Samuel, to push the contract through, and that the Attorney-General, the Chancellor of the Exchequer and the Postmaster-General had made immense fortunes by buying Marconi shares on inside information when they were cheap, and then selling them at the height of the boom.

Mr. Samuel heard these rumours in or about June, and Sir Rufus told him of his transactions in American Marconi shares. Mr. Samuel thought the information not very important, but he reported it to the Prime Minister, Mr. Asquith, who took a different view. He said 'our colleagues could not have done a more foolish thing'.

Meanwhile, the contract was signed and laid on the table of the House for ratification or rejection. Owing to the heavy pressure of business, the House was unable to find time to discuss the Marconi contract until August 7th, the last day before the summer recess. The Postmaster-General, Mr. Samuel, did not succeed in reassuring objectors to the contract, so it was agreed that the matter be held over until the autumn for debate. Some dissatisfied persons alleged that this date had been chosen in the hope that the matter would blow over during the summer holiday.

Mr. Samuel went to King's Cross station on the following day, August 8th, to take a train for Yorkshire. He observed on the bookstall a scurrilous weekly journal called the *Eye Witness*, edited by Cecil Chesterton, the brother of G. K. Chesterton. It contained an article entitled 'The Marconi Scandal', alleging that Mr. Godfrey Isaacs and Mr. Samuel had secretly arranged that the British people shall give the Marconi Company a very large sum of money through the agency of the said Samuel and for the benefit of the said Isaacs'.

Mr. Samuel immediately wrote to Sir Rufus that he thought the paper too contemptible to bother to take proceedings against, and shortly afterwards Sir Rufus wrote to the Prime Minister, putting the matter before him. Mr. Asquith replied that he had 'carefully read the scurrilous rubbish, and I am clearly of opinion that you should take no notice of it. . . .'

As the *Eye Witness* was not prosecuted, it followed up its earlier article with a long series on the Marconi Company by W. R. Lawson, a financial journalist. In September, Maxse in the *National Review* quoted Lawson's articles, and commented that 'in the face of their record of jobbery and robbery on a colossal and unprecedented scale, ministers can hardly be surprised at the currency of suspicion concerning their private concerns'.

The Marconi contract again came before the House of Commons on 11 October, 1912. Mr. Samuel moved that a Select Committee should be appointed to investigate the circumstances connected with the contract between the Marconi Company, Commendatore Marconi and the Postmaster-General. In the debate George Lansbury said that 'nobody ought to be in a position to make an agreement on behalf of the Government... in which, directly or indirectly, he may be interested'. These words seemed to be directed at Sir Rufus Isaacs, who immediately rose and denied that he had had any influence whatever in the placing of the contract, or that he had had dealings in the shares of the English Marconi Company. He did not mention his dealings in American Marconi shares.

Mr. Lloyd George demanded to know what the rumours were. 'The reason why the Government wanted a frank discussion before going to Committee was because we wanted to bring here these rumours, these sinister rumours, that had been passed from one foul lip to another behind the backs of the House.' Mr. Lloyd George also did not mention his dealings in American Marconis.

The Select Committee contained fifteen members, including seven Liberals, six Conservatives, and two Irish Nationalists. It continued its investigations for more than six months. Cabinet Ministers, civil servants, financiers, engineers, journalists, stockbrokers, were examined in detail. Twenty-nine thousand one hundred and seventy-six questions were asked. The reports of the proceedings contained nearly 2,000 double-columned quarto pages. Some of the information disclosed was astounding, but none was criminal.

In February 1913 Sir Rufus Isaacs and Mr. Samuel took legal action against *Le Matin*, which had alleged that they had been operating in British Marconi shares, while a contract was being negotiated. They retained the prominent Conservative lawyers Sir Edward Carson and Mr. F. E. Smith as their counsel, and the allegations were unreservedly withdrawn. Sir Rufus, however, took the opportunity of mentioning that he and Mr. Lloyd George had bought American Marconi shares.

The information made an enormous political sensation. The whole of the opposition press now concentrated on the affair, and interest in the activities of the Select Committee became intense. Sir Rufus and Mr. Lloyd George were examined by the Committee. The public was amazed to hear that the Ministers appeared to have made elementary mistakes of judgment in their personal financial activities. Both of them had endangered the Government and their own careers by comparatively trivial investments on which each of them had lost. Lloyd George's friends suggested that he was a child in stock-exchange transactions, but unfriendly critics commented that he was the Chancellor of the Exchequer, and it was most unfortunate that the finances of the nation should be in the hands of one apparently so unqualified. As for Sir Rufus, it was impossible to say that the greatest financial lawyer of the day was a child in such matters.

But as the months went by, the Committee's activities became more and more political. The opposite sides on the Committee became more interested in attacking each other than in furthering the investigation. In fact, they often seemed to be more concerned with discovering fresh ammunition for the party struggle, rather than in the objects for which the Committee had been set up.

The Conservatives scented the possibility of unseating the Government through the imprudence of Ministers. While the inquiry was in progress, the books of a stockbroker who had been 'hammered' on the Stock Exchange came into the hands of bankruptcy officials. It was noticed that this stockbroker had been conducting operations in Marconi shares for the Master of Elibank. The Committee examined the books, and it appeared that the Master of Elibank, who had been in charge of the Liberal Party's funds, had been investing part of these funds in Marconis under his own name on behalf of the Party.

The Master of Elibank was not himself available, as he had resigned from the position of Chief Whip, and departed on important private business to South America some two months after the Committee had been appointed.

Sir Rufus Isaacs and Mr. Lloyd George were requested to submit their bank pass books, and their wives', for examination.

Marconi offered on behalf of his company to withdraw from the contract. He gave the Committee a lengthy account of his career and company, in which he said that during the boom in their companies, he had never bought or sold a share. Neither he nor his company had been responsible in any way for the fluctuations in the prices of their shares, which had been due entirely to 'the natural supply and demand'. He could not conclude without expressing his resentment at the reflections on himself for innocently entering into a contract with His Majesty's Government. He resented the inquiry into the affairs of his company, and especially Mr. Godfrey Isaacs' business in America, which he entirely endorsed and confirmed. He regretted that the services his company had rendered for so many years to the British Government Departments, and 'in fact the whole nation', should not have been deemed worthy of higher consideration.

In reply to a question arising out of these remarks, Marconi added that he very much resented all the fuss which was being made over his name. 'You can go out any day and see on the placards "Marconi Scandal", "Marconi Manners", "Marconi Means", "Marconi Scenes", and I must say I most strongly object to my name being made a byword for party politics and a peg on which to hang all kinds of scandalous accusations, with which it is not suggested by anyone that I am in any way concerned.'

The Committee finally reported in June 1913, by a majority of 8 to 6, that the charges against the Ministers were 'absolutely untrue, and the persons responsible for their publication had no reason to believe them true'.

Lord Robert Cecil had submitted a draft, which was rejected, in which the Attorney-General was charged with 'grave impropriety'.

When the report was debated in the House of Commons, Sir Rufus said 'solemnly and sincerely that it was a mistake to purchase those shares'. Mr. Lloyd George made a remarkable speech in which he succeeded in giving an apology to the House without making any concession to the Opposition. He frankly admitted that 'it would have been infinitely better if the whole of the facts had been put before the House on October 11th'. He had then thought that explanation to the forthcoming Committee would be better, but events had shown 'it was a mistake in judgment'. He concluded by saying that he was not conscious of having done anything dishonourable. 'If you will, I acted thoughtlessly, I acted carelessly, I acted mistakenly, but I acted innocently, I acted openly, and I acted honestly.' The Prime Minister said that he thought the Ministers had acted innocently, but without sufficient prudence.

Finally the House resolved, after voting on strictly party lines, that it accepted the Ministers' expressions of regret, and acquitted them of acting otherwise than in good faith, and reprobated the charges of corruption which had proved wholly false. A few months later, Sir Rufus was promoted to be Lord Chief Justice. He subsequently became Viceroy of India. The Marconi affair had caused him great anguish, and he was never heard to refer to it again. The biographers of Mr. Asquith have recorded that he 'to the end of his days regarded this as the most difficult and painful personal incident that he had had to deal with in the course of his public life'.

The affair caused a year's delay in the ratification of the Marconi contract, with the consequence that the Imperial chain of wireless stations was not ready when the First World War began in 1914. At the end of that year, the Government cancelled the contract, and the Marconi Company received £600,000 damages. After Godfrey Isaacs undertook the business management of the Marconi companies they became far more prosperous. The American company, which up to 1911–12 had accumulated only an enormous deficit, produced a net profit of $211,246 in 1913.

Marconi's tenacity in this period of financial and political crisis was almost as striking as in the technical development of wireless. He had a very tough character, which did not arouse affection, but he had extraordinary courage. It was this quality which particularly appealed to some of the very able men who joined him in the early days, and stayed with him through thick and thin. His confidence in ultimate technical and commercial success, repeatedly confirmed by experience, had a greatness which overshadowed his unattractive qualities.

The military requirements of the First World War revived interest in short waves, and in 1916 he asked C. S. Franklin to re-examine the subject. In 1904 the wave-bands of less than 200 metres had been given to the amateurs to play with, because it was thought that only long waves could be effective for long-distance transmission. Amateurs found, however, that they could sometimes pick up small stations even 2,000 miles away.

By 1917 Franklin had designed mirrors made of wires, for reflecting waves of 3 to 15 metres, and radio communication between London and Birmingham was carried out with short-wave transmitters of less than one horse-power.

After the war, Marconi co-operated in these researches with his yacht *Elettra*. This graceful vessel, 220 feet long, had formerly belonged to an Austrian archduke. Marconi bought it in 1919, and fitted it as a floating home and laboratory. He cruised about the oceans, and found that his floating laboratory gave invaluable assistance in his next great advance in wireless communication.

Pursuing the research on short waves, Franklin produced much more powerful beams by placing a number of transmitting aerials at right-angles to the direction in which propagation was desired. He placed another row of wires behind these to act as reflectors. If the distance between the wires is small compared with the wavelength of the reflected waves, the grid of wires reflects the waves as if it were a continuous surface. The oscillations in the aerials were produced by radio valves, which by this time had been developed to produce powerful oscillations.

With this transmitting system strong beams of waves of 15 to 90 metres were directed at an angle of 10 or 15 degrees upwards. They were refracted down again by the ionosphere to receiving stations at great distances. Marconi tested the range and sharpness of definition of the beam by observations made on the *Elettra*.

Finally, in 1924, transmissions from Poldhu on 32-metre waves, using only about 12 h.p. of power, were received clearly in South America and Australia.

The Marconi Company had at last produced a system which could compete successfully with the submarine cables. It proposed to the British Government the construction of an Imperial Beam system of stations. This was accepted. The chain of short-wave stations was an immediate success, and cost very much less than a chain of long-wave stations.

Thus the sixteen years' delay in constructing the chain proved to be a blessing in disguise, in spite of the irritation and strain imposed by the long waiting, and the business and political friction. It saved the company from making heavy capital investments in long-wave stations which would have lost their value, and would have had to be written off.

The success of the short-wave system led the British Government to encourage the wireless and cable companies to combine; so after thirty-one years of independent activity, the Marconi Company became, in 1928, a part of *Cable and Wireless Ltd.* Subsequently, this company was nationalized.

Marconi's imagination and perseverance in short-wave development were very striking. He had experimented with beams of waves in his first experiments in the Villa Grifone. He had forecast in 1905 in a lecture to the Royal Institution that waves transmitted from England might somehow be concentrated in Australia, and that very little energy might be required to send messages in this way, so that the expense of the service would be correspondingly small.

He was always imaginatively aware of the extent of what remained to be discovered about electric waves, and of what they would or would not do. In 1921 he expressed serious interest in effects which seemed to be due to radio waves 'coming apparently from somewhere in space'. His alert attitude was entirely confirmed by Jansky's proof in 1932 that such waves do indeed arrive on the earth from outer space, and thus founded the brilliant new science of radio-astronomy.

In the same lecture Marconi forecast that in the next war (i.e. the Second World War), radio would be used in producing 'horrors', such as wireless-controlled weapons. But if such developments came about, he said, 'the means of combating and counteracting them would quickly be found'. The swift development of radar to counteract aircraft, and proximity fuses to destroy flying bombs was a confirmation of his remarkable prescience.

In his last years, he again looked to the future, for he concentrated on the investigation of the possibilities of very short waves of centimetre length. Once more his foresight was demonstrated, for the greatest triumphs of radar arose out of the application of these very short waves.

In the light of his previous career, circumstances and temperament, it is perhaps not surprising to learn that Marconi supported the Italian Fascist Party, from the early date of 1923. In 1927 he told American reporters that Mussolini's 'bold, audacious, political and financial policies have transformed' Italy.

After the dissolution of his first marriage by Papal Dispensation in 1927, Marconi married the young and beautiful Countess Maria Cristina Bezzi-Scali. She spoke on behalf of the Italian fascists, saying that it was only since their advent that the '5,000,000 working women in Italy' were 'on an absolute equality with men—equal work, equal pay'.

Marconi was appointed a member of the Fascist Grand Council in 1930, and President of the Italian Academy of Sciences. He was given a score of knighthoods and similar orders, and another score of honorary degrees. In addition to the Nobel Prize, he was awarded more than a score of other scientific prizes and medals.

Marconi died on 20 July 1937, on the fortieth anniversary, to the very day, of the foundation of his famous wireless company. He could never be a popular man, but he was one of the greatest of inventors. In his first years he personally devised new apparatus of fundamental practical importance. Then he gradually changed into the leader of a team of wireless research engineers. In this field, demanding quite different qualities, he was repeatedly and equally successful. Through the whole of his forty years with his company, his commanding imagination, prescience in the face of scientific conservatism, persistence in spite of continual business and political turmoil, and his unflagging passion for research and bold new ideas, dominated his colleagues and wireless development.

He was an inventor of the obsessional type, with one overmastering interest—wireless. Others surpassed him in particular fields. For instance, no single invention of his was as brilliant as Lee de Forest's grid which converted Fleming's diode valve into the modern Protean radio valve, which made modern sound broadcasting and many other things possible. But Lee de Forest was of the maniacal type; he could not co-operate with anyone, nor stick to anything. He sprang from one brilliant idea in one field to another equally brilliant in quite another field. The companies founded to exploit his inventions failed.

The full greatness of Marconi is seen in his command over the complete range of wireless development. His achievement as a whole was incomparable in his field.

He was magnificently successful, but at a high cost in certain human qualities. Perhaps it was impossible for this to be otherwise in the times in which he lived.

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THE WRIGHT BROTHERS

WILBUR WRIGHT *ORVILLE WRIGHT*

1867–1912 *1871–1948*

WILBUR WRIGHT was born on 16 April 1867, and his brother Orville on 19 August 1871. They were the two youngest of the four sons of the Reverend Milton Wright, a minister in the manufacturing town of Dayton, Ohio.

The Reverend Milton Wright became a bishop of the United Brethren Church, a small nonconformist community in the American Middle West. He was a kindly, broad-minded, cultivated man, with strict rules of conduct which he did not impose on others. He had a good library, and encouraged his children in reading, and in all useful initiative. His income as the head of his religious community was only about £200 a year. It was natural that he should rear his family with economical habits and simple virtues. One of his first satisfactions on hearing of Wilbur's flights in France, which were receiving the rapturous applause of kings and the whole world, was that Wilbur had preserved Sunday observance, refusing always to fly on the Sabbath, and had not succumbed to smoking. This was worth more, he said, than all the money that they would make out of their invention.

He was always warning his sons of the vanity of riches. No doubt as a consequence of this, Wilbur and Orville handled their financial affairs with intelligent detachment, and never subordinated their aims to a grasping desire for gain.

Bishop Wright's economies continued after they were no longer necessary. Wilbur once took the trouble to write from Europe that his father must not be allowed to switch off his electric fan at night during a heat wave, in order to save money, but must keep it going continually.

Mr. Wright followed every aspect of his children's life, and fortunately lived to see Wilbur and Orville achieve their full fame. In his affectionate understanding, the old clergyman, who wore a long beard like a patriarch, preserved every detail about all the members of his family. Because of this habit, the documentation of the Wright achievement is one of the fullest in the history of invention. The Wright papers deposited in the U.S. Library of Congress contain no fewer than thirty thousand items. No comprehensive analysis of them was published until 1953, and some of the items will still not be available for public inspection until 1960. The most important features of the story of the Wright brothers have become clear only gradually during the last thirty years.

The Wright brothers were brought up to be fundamentally well-educated, and independent in their point of view. They remained so to the end, remarkably unaltered by success.

They were descended on their father's side from the Wrights of Kelvedon Hall in Essex. Their mother was a daughter of a German wheelwright who had emigrated to America to escape from German autocracy. She was noted for her practical skill, and even undertook carpentry, such as making a sledge for her children. Making and adapting things was a habit in the Wright household. Their father's income was so small that if things were to be had at all, they usually had to be made at home. Wilbur and Orville carried out considerable structural changes in the interior of the house when they were boys. All the family took interest and pride in these activities.

The need for mutual help in the household was increased by the failure of Mrs. Wright's health. In middle life she became an invalid, and her children had to help yet more in the household chores.

Wilbur was particularly fond of reading when he was a boy, and was very athletic. He was a brilliant figure-skater. In his 'teens, however, he had a serious accident while playing ice-hockey. He received a tremendous blow in the mouth, which knocked out all his upper front teeth. The shock left him with a disorder of the heart from which he did not recover for many years. The loss of his teeth gave him a grim expression which was a misleading guide to his character.

Because of his accident, his schooling was interrupted. He stayed at home a great deal, helping to look after his invalid mother, and did not engage in out-of-door occupations. Mrs. Wright died in 1889, and his father said that Wilbur's attentions had probably extended his mother's life by two years. Being at home when the rest of the family was away, he read more than ever.

Orville was four years his junior. He was named after a Unitarian minister whom his father admired. He was inclined to be mischievous, and played truant from school. He showed signs of leadership among his playmates. As he was considerably younger than Wilbur he was not at first very close to him; their deep fraternal understanding came later.

The unique bond of intellectual collaboration was not based on similarity of temperament, but rather on contrast. They were complementary to each other. Apart from their passionate interest in the same thing, almost the only characteristic they had in common was grey-blue eyes. Orville resembled his mother, and was meticulous over his clothes. Wilbur was more like his father, and perfunctory about his appearance. The extraordinary collaboration between the two brothers, unparalleled in the history of science, seemed to some extent to be a repetition in the realm of intellectual understanding of the deep affection that had united their father and mother.

The earliest Wright document is a letter of Orville's written when he was nine. It contains a reference to an experiment in which a tin of water was boiled on a stove, so that water and vapour shot out.

Wilbur attended a secondary school, but did not bother to collect a certificate. He had some grounding in Latin, Greek and trigonometry, but did not learn French. Out of school hours, in the usual American way, he did various odd jobs, for which he received small payments. One of these jobs was the folding of the copies of the church paper. Finding this work tedious, he invented a folding-machine to do it for him.

In his reading he browsed through every section of his father's collection of books, theological and philosophical. In general reading, he and Orville were fond of Grimm's and Andersen's fairy tales, Plutarch's *Lives*, Addison's essays, Scott's novels, Gibbon's *Decline and Fall*, Green's history of England, and Guizot's *France*. Their scientific reading was mostly in the articles of the *Encyclopædia Britannica* and *Chamber's*, and one book important for their future: Marey's *Animal Mechanism*. Orville read the scientific articles almost as soon as he had learned to read. Wilbur was more interested in general ideas.

Like many American boys, the brothers started their own newspaper. They wrote and printed a little paper which they circulated and sold among their acquaintances. It was initiated by Orville, more from the mechanical interest of setting up and printing, than from writing. Orville never became a fluent writer, though he could express himself well when it was necessary. He brought in Wilbur, who contributed humorous articles, to help with the writing. Wilbur was from his earliest days a fluent writer. He grew into a great one. His scientific papers subsequently revealed a magnificent style and intellectual power.

One of Orville's schoolfriends was Paul Lawrence Dunbar, the famous Negro poet. Dunbar started a paper for Negro readers in 1890, which Orville printed.

Bishop Wright's two older sons presently left the family house to start their own homes. The widowed father and his two younger sons and daughter drew yet more closely together. They formed a family group of exceptional understanding. Neither Wilbur nor Orville nor their sister Katherine ever married, nor did they ever depart from Dayton as their home. Their affections were deeply engaged among themselves. They had an extraordinary cohesion, which continued through all the great affairs in which they were subsequently involved.

In his later years, Orville was often invited to represent the achievement of Wilbur and himself as the result of the efforts of two enterprising American boys, who, without any particular advantages, had set out to make their fortunes. He resolutely refused to countenance this, and denied that Wilbur and himself ever had any thought of making money when they began their aeronautical activities. It was not true that they had had no particular advantages. On the contrary, they had had the very special advantage of an exceptionally happy and intelligent home life. They had been admirably reared, and given every encouragement to pursue intellectual and constructive interests, and to satisfy their curiosity. He considered that they could not have had a greater advantage than this mutual understanding, which had encouraged them to pursue their own ideas with profound confidence.

The Wright boys' interest turned from journalism to bicycles in 1892, when the 'safety' type, with two equal wheels, was introduced into America. They decided to set up a shop for selling well-known makes. This prospered, and they soon added to their retail business repairing, and then the manufacturing of their own makes.

They built their bicycles during the winter months, when sales were slack in the hard Middle Western winter. With their simple workshop appliances they made odd things that they happened to think of. In 1895, Orville devised a calculating machine, and a simplified typewriter.

As their bicycles appealed particularly to the boys and girls in the local schools, Wilbur composed advertisements in the form of school examination papers. These were a series of questions, the correct answer to all of which was a Wright bicycle!

The brothers worked together in complete harmony. They had a joint bank account, and at home, where they were often alone together for long periods, each undertook the cooking on alternate weeks. From their early days, they were completely self-sufficient. This characteristic of doing everything became more and more striking as their work became more and more important.

Though the brothers were already supporting themselves, Wilbur felt that he was not specially fitted for business, and wrote to his father in 1894, asking him for a loan of £30 to help him to pursue a higher education. He said that intellectual effort was a pleasure to him, and fitted him for the professions better than for commerce. His father agreed to make the loan. However, the general family circumstances were too straitened to allow Wilbur to go to college with a quiet conscience, so he relinquished this aim. But he never lost the intention of securing the conditions which would enable him to devote all of his efforts to scientific research. Orville had the same aspiration. After Wilbur died in 1912, he sold his industrial interests as quickly as he could get a good price for them, and retired in 1915. For the next thirty-three years he worked in his own private laboratory, on such problems as he chose. He did not discover anything of great importance. The collaboration with his brother, which had fertilized his genius, had been ended, and his inherent creativeness languished in isolation.

The first interest of the brothers in flight had been aroused in 1878, when they were small children. Their father brought home one day a little model flying bat. This was one of the toy flying-machines invented by the brilliant and ill-fated Pénaud, who first introduced rubber bands for driving propellers, and made the first inherently stable model flying-machines. Lack of appreciation caused him to commit suicide at the age of thirty. The Wright boys never forgot his ingenious inventions.

Their first adult interest in flight was aroused in 1895, by an article they happened to read on Otto Lilienthal of Berlin. His soaring in the air in gliders struck them as a new sport which was far more exciting than any other. They began their serious study of flight entirely from this sporting motive.

The news in the following year that Lilienthal had been killed in an accident greatly increased their curiosity. They wondered what the cause of the accident might have been, and how it could have been avoided.

They searched the Dayton public library for literature on flight, and found little that was helpful. Having heard of Professor S. P. Langley's aviation researches, Wilbur wrote in 1899 to the Smithsonian Institution at Washington, of which Langley was Secretary, for advice on the literature of the subject. This first letter already had the mark of genius. Wilbur mentioned that he had been interested in flight ever since he had made flying models after the designs of Cayley and Pénaud. His own observations had convinced him still more firmly that human flight was possible and practicable. It was only a question of knowledge and skill, as in other acrobatic feats (Wilbur had himself been a considerable gymnast). Birds were the most perfectly trained gymnasts, and some of their feats required about four times as much effort as ordinary flight. The birds' very big reserve of power made him believe that, even if man would never equal the bird in flying gymnastics, he might find the very much lower demands of simple flight within his modest powers. He was convinced that the solution of the problem would be derived from the accumulated knowledge and skill of many independent workers. He was an enthusiast, not a crank with a pet theory of his own. He wished to learn all that was already known, so that he could add his mite towards the future achievement of human flight.

The Smithsonian recommended a list which included works by Chanute on the history of flying and Langley on aerodynamics, and sent a number of pamphlets, in particular Lilienthal on 'The Problem of Flying and Practical Experiments in Soaring'. At the time when this material arrived, their sister Katherine happened to come back from college for a holiday, and brought a girl friend with her, hoping that she would be entertained by Wilbur and Orville. But the two young men were so absorbed in the flying literature that they were scarcely conscious of her presence.

Years afterwards, Wilbur described how they were impressed, on reading these works, by the immense quantity of effort and money which had been spent on futile attempts to fly. They had imagined that the problem had not been solved because it had never been attacked by men of the greatest ability. They had learned, on the contrary, that scientific and inventive geniuses of the first order had attempted it, from Leonardo da Vinci, the greatest universal genius that had yet appeared, to such eminent scientists and engineers as Cayley, Langley, Bell, Maxim, Chanute, Parsons, Edison, Lilienthal, and many others. All of these great men had been defeated by the problem.

The brothers began to study their failures, and found that these were very suggestive. Of all their predecessors' work, they esteemed Lilienthal's the most, because he had done a great deal of practical gliding in the air, and had also made extensive scientific measurements of air pressures on wings. But they calculated that even Lilienthal could not have spent more than five hours in the air during the whole five years of his experiments. Evidently, if the problem of flight was to be solved, experimenters would have to discover how to stay in the air longer. It was only when the experimenter could stay in the air for a reasonable time that he could find out, without being flurried, what was necessary to cope with the various flying difficulties which had hitherto brought gliders down after a few seconds.

It became clear, as Wilbur afterwards said, that the preserving of the equilibrium of the machine, so that it could stay up for considerable periods, was the fundamental problem of flight, and not the building of light and strong frames, or of light and powerful engines.

None of their predecessors had evolved a complete mechanical system for preserving the equilibrium of their machines. Lilienthal had depended in part on moving the weight of his body to right his glider. No one had worked out a system for correcting rolling. Pondering on this problem, Orville saw that it might be solved if the tip of the opposite ends of the wings could be bent so that they presented inclinations to the air which were different from that of the main part of the wings.

This notion contains the idea of the aileron, or movable flap, since used in all aeroplanes. It became the fundamental part of the original Wright patent, which was subsequently upheld in all legal judgments.

In the Wright system, the position of the centre of gravity of the machine remains constant, and its equilibrium is maintained by varying the air pressures on its various surfaces.

Some six weeks later, Wilbur thought of a way of carrying out Orville's idea. He noticed in handling a long, limp rectangular cardboard box in their cycle shop that while its small ends remained rigid, he could twist the box around its long axis, so that the inclinations of the broad sides were in opposite directions at the opposite ends. He suggested that they might warp the wing surfaces of a two-winged box-shaped glider in the same way, without losing structural strength.

Within three months of receiving their collection of literature, they began to make a box-kite to test their ideas. It contained two wings, one on top of the other, about five feet long. These could be warped, as the kite was flying in the air, by means of cords operated from the ground. They found that their warping invention gave them a much increased command of the equilibrium of the kite.

At the end of 1899, the brothers wrote to the Weather Bureau at Washington for information about the wind velocity at various places in the United States. Then, in the spring of 1900, Wilbur wrote to Chanute in Chicago about plans for a man-carrying kite. He thought that such a kite would be able to stay in the air for long periods, so that the operator could have hours of experience in manipulating it, compared with the seconds of those who had hitherto made gliding experiments. He asked Chanute for advice about the best places for such kite-flying, and Chanute recommended the sand-hills off the Atlantic coast.

Chanute gave the Wrights immediate and steadfast encouragement. He was a civil engineer of high standing, who had built the stockyards in Chicago, and many other great constructions. His articles on the history of aviation contained the best collection of information on flight up to that date. He had also made gliding experiments himself, and was well-to-do. In addition to all this, he had a correct grasp of the combination of qualities required for the solution of the problem of flying. He had said, in 1890, that an association of workers was required, for it was unlikely that one man could simultaneously invent new structures and new engines.

He could not be at once a mechanical engineer to design the apparatus, a mathematician to calculate its stresses, a practical engineer to make the parts, and a syndicate of capitalists to provide the funds. Progress had been so slow, he thought, because so great a variety of talent was necessary to solve every aspect of the problem.

The Wrights no doubt benefited from being in close contact with an eminent engineer who had so just an appreciation of the qualities required to solve the problem of flight. As they saw that equilibrium of the aircraft was the primary problem in flight, so, too, they were able to see that equilibrium was also the primary problem in the arrangement in their plan of research. They were never led away to believe that the solution was primarily a matter of gliding practice, or mathematical calculation, or of engine power, or of frame construction, but always comprehended that it depended on a complicated and judicious balance of all of these.

It proved that the Wright brothers contained within themselves all of the many necessary aptitudes, and were able to combine these to achieve the required result.

After they had dealt with the rush of spring sales of their bicycles in 1900, the brothers devoted a great deal of thought to ways of improving stability. They spent long hours imagining various modifications of their design, and calculating their possibilities. They concluded that an elevator placed in front of the wings should increase stability.

In August they began the construction of a man-carrying glider based on the results of their thought and calculations. The total cost of the materials was about three pounds. They intended to fly it first as a kite, in order to master its operation, and then fly it as a glider. For this they needed open country, free from trees and obstructions, with steady winds. By gliding into the wind, the speed of the glider relative to the ground would be small, and the danger to the pilot much less.

They examined the list of places sent by the Bureau. One of these was Kitty Hawk, a very lonely, out-of-the-way beach on the great sand-bar off the coast of North Carolina, where Sir Walter Raleigh's ill-fated colonists had been lost three centuries before. The Wrights were attracted to it because it was only a thousand miles from Dayton, much nearer than the other promising places. They wrote to Kitty Hawk for further information, and learned that there were great spaces of sand with occasional hills up to about a hundred feet high, and no trees. Nearby was a lifeboat and coastguard station, and a few residents, casual fishermen and beach-combers. Wilbur's letter was taken to the most educated man in the locality, the husband of the postmistress. He gave a very graphic and useful description of the place, which convinced the Wrights of its suitability.

Wilbur set out in September to explore Kitty Hawk. He found that he had to take a forty-mile boat trip from the nearest town on the coast in order to reach it. He was unable to get anything better than a leaky old boat, which took two days over the passage. It was so filthy that he could not bring himself to eat in it.

When he at last arrived at the desolate place, he was received most hospitably. The postmistress put him up in her house. The inhabitants were at first greatly impressed by Wilbur as a person who appeared to be able to devote weeks of time to a sport. They thought he must be a rich man. Then they were impressed by his skill. He assembled the glider, and cut and resewed the sateen covering to fit the wings. He did the sewing on the postmistress's sewing-machine.

He set up a tent on the sand, to accommodate the glider and his tools, and awaited Orville's arrival later in the month. As there was not room for both in the postmistress's house, they camped out in the tent. Orville did the cooking, and Wilbur the washing-up. They baked a kind of biscuit instead of bread. Milk was unobtainable.

When the glider was assembled, it weighed 52 lb. and had a span of about 17½ feet. It was fitted with an elevator in front, and the wings could be warped. They found immediately that its lifting power was far less than it should have been according to the figures of Lilienthal's table of air-pressures on flying-wings, which they had used in calculating its design. They accordingly decided to fly it first as a kite, carrying only a weight of 50 lb., and then with a man aboard.

After they had made satisfactory kite trials, they decided to try glides down the side of one of the sandy slopes, with the wind blowing up the hill. The machine went down at about thirty miles an hour, and the wind came up at about fifteen miles an hour, so the speed of the machine relative to the ground was only fifteen miles an hour. It was usually only about two or three feet off the sand. The Wrights always paid the most meticulous attention to safety.

By the time that they had to conclude their first visit to Kitty Hawk, the Wrights found that they had spent altogether only ten minutes in the air in their machine flown as a kite, and only two minutes in the air in gliding, instead of the total of hours which they had expected. But they had found that their machine was more stable than any before made, and could be controlled mechanically, without shifting their own weight.

They decided to build a bigger glider, and did not bother to take the old machine back to Dayton. The postmistress made dresses for her two little girls out of the sateen from its wings.

During the winter of 1900–01 they designed the new machine, and gave its wings a bigger hump, or camber. Chanute called to see them at Dayton. He gave them more encouragement, and offered them financial support. The Wrights never accepted any financial assistance. They made a profit of about £600 a year out of their cycle business, which provided them with all the modest surplus that they needed. They were very wise in this, for in later years Chanute complained that they had not given sufficient credit to him for his encouragement. If he had had a financial interest in their work, the Wrights might have lost control of their invention, and the development of aviation have been deprived of the guidance which their genius gave it.

When the Wrights arrived at Kitty Hawk in the autumn of 1901 they found that their new, big glider was not as good as their old one. They discovered that this was due to the bigger hump or camber of the wings. When this was flattened down again, the glider behaved much better.

While gliding with this machine, the brothers discovered that if a wing was turned upward, so that its underside caught the wind, it did not necessarily tend to rise. They found that this was because the more broadside-on presentation to the air reduced the wing's speed through the air, and hence its lifting power. Thus turning the wing up might cause the wing as a whole to go down. They decided to fix a vertical fin in the rear of the glider to counter this effect.

They discovered in this series of glides that the centre of the wind-pressure on the glider did not behave as previous investigators had supposed. It was universally believed, on the basis of many experiments, that when the inclination of the wing to the horizontal increases, then the centre of air pressure on the wing always moved toward the forward edge. The importance of this for keeping the glider in equilibrium was fundamental, for it was obvious that one of the pilot's chief functions was to manage the glider so that the pressure of the wind did not act in such a way as to upset it. The brothers discovered that if the inclination of the wing was small, then a further decrease in inclination might cause the centre of pressure to move towards the rear edge of the wing.

This discovery was of extreme importance, because it enabled them to design a glider that would be stable and safe. Other experimenters were, through ignorance, liable to operate their gliders in certain situations so that they were bound to come down. Unknown to themselves, they were upsetting their machines, and involving themselves in crashes.

The brothers confirmed their discovery by experimenting with a surface held out from their machine, while gliding in the air.

These glides made in the sandy wastes of Kitty Hawk cost much in comfort. The complete lack of fresh milk created a great thirst for it. The mosquitoes at night were so bad that it was often impossible to sleep. The brothers nearly abandoned their whole effort to fly through this reason alone.

Their experiments of this summer had convinced them that it was possible to make a big glider which could be controlled mechanically in the air, without the pilot having to use his own weight. This was of fundamental importance, for all previous gliders had been small, because the force which could be exerted by the pilot through the moving of the weight of his own body was too small to control a large machine.

The old restriction to small sizes of gliders had seemed to make the possibility of a machine driven by an engine very remote, for the old, small gliders were not big enough to support an engine in the air.

Having discovered how to control big gliders, the brothers now knew that it was possible to manage one large enough to carry an engine. This was a tremendous advance. Nevertheless, the first effect of the summer's experiments was to fill the brothers with depression. They were deeply shocked by their discovery of the fundamental deficiency of all their predecessors in knowledge of centres of pressure. If these men were wrong, then the whole of the existing scientific knowledge of aviation was suspect. They feared that many other pitfalls might exist, which would cause experimenters to be killed before they had been discovered, so that flying could never become safe.

After their wonderful summer's work, Wilbur remarked on the way home to Dayton that he believed that not within the next thousand years would man learn to fly.

At this stage, Chanute again revived the brother's confidence, and urged them not to lose heart. He invited Wilbur to give a lecture on their experiments to the Western Society of Engineers in Chicago. This was Wilbur's first lecture. He exposed the extraordinary mistakes they had discovered in the existing data of air-pressures on wings.

While Wilbur was in Chicago, Orville became nervous about their outspoken criticisms, and began to wonder whether, after all, they might not have been mistaken. Had not all the leading men in the world accepted the old figures? Were Wilbur and himself perhaps making fools of themselves?

He hastily set up a tiny wind-tunnel only about one and a half feet long, to make some tests on model wings. After only one day's experiments, he obtained confirmatory evidence that some of the accepted figures were wrong.

After Wilbur returned from Chicago, the brothers decided that though the one day's experiments increased their confidence that their criticisms were sound, it would be wiser to tone down the published version of Wilbur's lecture. Even so, this version, published in December 1901, became perhaps the most quoted of all scientific papers on aeronautics. It was published two years before the Wrights made their first flight in an engine-driven aeroplane.

At this point, the brothers were not sure whether they would pursue any more practical gliding experiments. They became more interested in the mistakes they had discovered in aeronautical science than in the practical problem of flying, and they thought of devoting themselves entirely to investigating the scientific problems that they had uncovered.

They built a wind-tunnel about six feet long, and sixteen inches square; they set it up in their cycle works. They drove air through it by a fan revolved by a one-horse-power gas engine, which they had used for driving grinding-wheels. They sent the wind through perforations, so that the draught in the tunnel was steady, and free from turbulence.

In a period of about two months they tested the properties of more than two hundred shapes of model-wing surfaces. These were made by hammering pieces of steel-sheet into the required shape on an anvil. They systematically plotted, on finely-drawn graphs, the results of slight changes of inclination of the wings to the wind-stream over a wide range of angles. They investigated the behaviour of single wings as in a monoplane, of two wings one above the other as in a biplane, and of three wings as in a triplane. Among their host of marvellous and unexpected results, they found that a simple square plane surface inclined at thirty degrees produced a bigger pressure than one more broadside-on at forty-five degrees. They found that wings should not have a sharp front edge, but should be rounded, or as is said nowadays, stream-lined.

They noticed that if things were moved about in the workshop where the tunnel was set up, the stream inside the tunnel was disturbed. So they kept everything in the workshop most carefully in its proper place, and always stood themselves in exactly the same position beside the tunnel when taking observations.

They constructed instruments out of the wire of bicycle spokes, and pieces of hack-saw blades, to measure the forces exerted on their model-wing surfaces. The experimental procedure that they adopted enabled them to make accurate deductions about the design of full-sized wings from their models. They were so fascinated by their results that they often worked on the experiments until the early hours of the morning.

These wind-tunnel experiments of the Wright brothers are among the most brilliant in the history of experimental science. In them they measured all but one of the fundamental factors governing the properties of aeroplane wings. Most subsequent research in this field has been mainly an extension of their methods and results.

All this was done in a few weeks in the intervals which they could spare from their cycle business. More than thirty years passed before the correctness of their experimental procedure was completely proved by mathematics.

The brothers gave a full account of these experiments to one or two of their close personal friends. The extent and profundity of their results remained generally unknown until 1939, when they were expounded by W. G. Lewis in a Wilbur Wright memorial lecture.

The Wrights kept their fundamental results secret as they did not feel sufficiently protected by the patent system. This private fundamental scientific knowledge enabled them to make practical performances whose superiority to all that had been done before seemed quite inexplicable.

When the great engineer H. V. Lanchester met Wilbur Wright during his first flights in France, he asked him some scientific questions about the principles of his machine. Wilbur evaded answering them, and Lanchester concluded that he was a pure empiric, and that he and Orville had made the first successful power-driven aeroplane by happy chance.

This belief became established, and the reluctance of the Wrights to publish their fundamental investigations led to a widespread misconception of the nature of their achievement. They were believed to be bicycle-makers without scientific or engineering education who had hit upon the solution of a great problem by good luck.

There has not been a bigger misconception in the history of invention. The Wright brothers, though they had never received any scientific and engineering training, adopted a fundamentally scientific approach to their problem. They had, of course, natural scientific and engineering gifts of the highest order. But these were by themselves not sufficient.

One of their motives for pursuing their wind-tunnel experiments was economy. They had the idea of trying to solve as many of their problems as possible in the study and the workshop, before they went into the air. They were modest bicycle-makers, with only a few dollars to spare for their hobby. They could not afford to build expensive machines which immediately crashed.

Another of their leading motives was safety. Wilbur repeatedly assured his father that they were taking all precautions. The brothers carried out very thorough tests of the strength of all the wood, metal, and materials used in their machines. They placed whole gliders with the tips of their wings on supports, and then submitted them to far greater forces than they would have to bear in flight.

Where did all this genius come from? Wilbur himself subsequently discussed the question. He wrote to Chanute that great inventions depended on much more than the single point of mental ability. Why had fifty years passed before James Watt improved upon Newcomen's engine?

In his opinion it was assuredly not due to lack of men of ability. There were plenty of men in that period of fifty years as gifted as Watt. But none of them found himself in the right combination of circumstances. The only aspect of the work of Orville and himself that struck him as remarkable was the short period in which they had solved the problem of flight; in their spare time of only four years. If they had started on it a little earlier or a little later, they would probably not have succeeded. It was the peculiar combination of circumstances, their age, modest prosperity, mechanical nature of their occupation, useful workshop resources, seasonal trade which enabled them to go to the coast for considerable periods, a home-life that had established valuable social habits and attitudes and encouraged intellectual interests, an unparalleled intellectual debate and co-operation between two brothers of great but different scientific gifts.

These were the kinds of circumstances which were the condition of their success. Given such a combination of circumstances, their achievement was predictable. In fact, Wilbur wrote to Chanute, it was not a question of relative ability, but mathematically calculable probability as to what would arise out of a particular concatenation of circumstances.

Wilbur's deprecation of the attribution of their success purely to personal mental ability, or undefined genius, makes his comments on the nature of the origin of invention all the more authoritative, for men are not generally predisposed to underrate the contribution from their own mental gifts.

On the basis of their gliding experience and their wind-tunnel experiments the brothers built a new glider. It was about twice as efficient aerodynamically as the best of preceding gliders. They took it to Kitty Hawk, and during the autumn made more than one thousand glides with it, some in winds as high as thirty-six miles per hour.

The new machine had a fixed vertical tail. They found that about one flight in fifty ended in a tail-spin. Orville thought out what was happening during long sleepless hours in bed. He had a strong geometrical imagination, and could visualize in his mind the movements of surfaces and the actions of forces on them. He concluded that the spinning movement could be stopped if the tail were converted from a fixed into a movable surface.

The 1902 glider and its system of control formed the basis of their aviation patent. This master patent, which gave the Wrights control over the development of aviation in every country where it was granted, was filed early in 1903, before they had made a flying-machine driven by an engine. So far as materials were concerned, this glider could have been made at any time during the last thousand years. It required nothing more than wood and cloth and string. The experimental method by which it was worked out was, however, a product of centuries of science and technology.

After the success with their big glider, and when they had recovered from the shock of their discovery of the degree of the inadequacy of the preceding scientific data on aerodynamics, the brothers started on the design of a power-driven aeroplane. They approached this stage of their task with much confidence. They had discovered that the engine was not the most important part of an aeroplane. All that their engine would have to do was to keep their large glider in the air, and the glider could almost keep itself in the air already. If birds could soar without an engine, that is, when they were using their wings merely for gliding, why shouldn't an aerodynamically efficient glider soar without an engine, or at least with not more than a small one?

At the end of 1902 the brothers tried to buy a petrol engine which would develop 8 h.p. and weigh not more than 200 lb. This was a modest demand, but no company was able to supply them with one, so they set about making their own. They constructed a four-cylinder engine, with the four cylinders lying horizontally side by side. It weighed 170 lb. and easily developed 12 h.p. They had not asked for much and had got more than they had calculated would be necessary.

They calculated from their data that the wings of the machine should have a span of at least forty feet, if it was to carry both a pilot and an engine, each of about the same weight.

The brothers left the problem of designing the propellers to the end. They assumed that they could easily make them on the lines of the propellers for driving ships. They got books from the Dayton public library on marine propellers, but were surprised to find on reading them that little was known about the theory of marine propellers. Their shape was not calculated from theory, but based on long experience. As there were virtually no recorded data on the performance of propellers working in air, they could not base their design merely on the past experience of others.

The brothers found themselves held up by this unexpected difficulty. They pondered and discussed the nature of propellers for many weeks, and tried to work out their properties from first principles. Their genius led them to approach the problem in an entirely new, profound, and scientifically correct manner. They saw that the blade of a propeller is really an aeroplane wing being whirled round in a circle. They ought therefore to be able to calculate the thrust, which was the same in principle as the lifting power of a wing, to be obtained from various shapes and inclinations of blades, from the aerodynamical data they had collected in their gliding and wind-tunnel experiments on wings.

In their long analytical discussions of these problems, Orville used to sit with his arms folded in a chair on one side of the sitting-room stove, and Wilbur sprawled out in a chair on the other side, lounging on the small of his back, and resting his head on the palms of his intertwining hands.

The brothers succeeded in calculating the thrust of their propellers to within about one per cent, and evolved a design which was about thirty per cent more efficient than those previously made by Maxim and Langley.

By September 1903, their machine was constructed, and they set out for Kitty Hawk for the trials. Both men were confident, and at the height of their physical and mental powers. Wilbur was thirty-six years old and Orville thirty-two. They were wiry, and weighed only about nine stone, being admirably built for experimental flyers.

While they assembled their new machine, they also got some flying practice on their old glider. The weather, however, became very bad. Their machine was nearly blown away in a 75 m.p.h. gale. When the assembly was complete, they began to test their engine. They at once ran into trouble, for the shafts driving the propellers broke down. Chanute came to watch their progress, but he found the rough camping conditions in the cold wintry weather too uncomfortable in the long delay caused by the shaft breakdowns, and left after a week.

The brothers received new and better shafts from Dayton at the end of November. They had already been in the stormy and cold sandy wastes for two months, away from their cycle business. By the time that they were nearly ready for their first attempt at power-driven flight, snow and sleet blown by a stiff northerly breeze, set in for several days.

Again their shafts broke down, so Orville went personally to Dayton to secure new ones made of solid tool steel. On the way back to Kitty Hawk, he read an account in a newspaper of the final disaster to Langley's flying machine on 8 December 1903, when it fell from the launching mechanism straight into the river Potomac.

This failure by one of the best-known scientists in America, who had been substantially supported by Government and Institution funds, at once emphasized the difficulty of what the Wrights were attempting, and also spurred them on to try.

The brothers impatiently waited for the weather to improve, as they wished to be home for Christmas. On December 14th, the weather was very clear, though freezing. As there was little wind, they decided to try to rise from the side of one of the dunes. The brothers tossed as to who should be pilot, and Wilbur won. Half a dozen of the local inhabitants helped them to drag the machine to the launching gear. This consisted of a long wooden rail. A small wheeled truck, with ball-bearings made from bicycle hubs, ran on the rail, and carried the flying machine.

The brothers fixed the machine on the gear, and set the engine going. Wilbur lay down in the pilot's place, and released a catch so that the propellers could push the plane on its truck along the rail, until it had acquired enough speed to lift. But the plane lifted too quickly, stalled, and fell to the ground after less than four seconds. Some minor damage was done. The brothers agreed not to count this trial, and waited for another opportunity.

On December 17th, the puddles around their camp were covered with ice, and there was a wind of nearly thirty miles an hour. They expected it would die down, so that they could make another attempt later in the day. But the wind did not fall, so they decided to make an attempt in spite of it. It was Orville's turn. The plane was got ready in the biting cold, and the engine was run to warm it up. Orville lay in the pilot's place, while several coastguards and one or two of the local inhabitants watched.

The launching gear was directed so that the machine was pushed by its propellers into the 27 m.p.h. wind. Its speed relative to the ground was low, and Wilbur ran beside it for forty feet, steadying the edge of the wing until the machine began to lift into the air. The brothers had focused a camera on the space just beyond the end of the starting rail, and had arranged with one of the coastguards to snap the machine as soon as it had left the ground. The coastguard did this successfully, and thereby made the most famous picture in aviation.

The plane came down about 120 feet from the starting point, after a flight of twelve seconds. It was the first flight by an engine-driven, piloted aeroplane, which left the ground under its own power, sustained its speed in the air, and landed at a point as high as its starting place. Three more flights were made during the morning, and on the last, Wilbur flew 852 feet in 59 seconds.

After preparing their lunch, and washing up, the brothers went to the coastguard station to telegraph their success to their father. While the telegram was in transmission to Dayton, an operator communicated the information, flatly against the Wrights' instructions, to a local newspaper in Norfolk, Virginia. A fantastically inaccurate account of what had happened was written up in the newspaper office, and published. The editor offered a paragraph on the story to twenty-one other papers. Only three in the United States reproduced it the next morning, and one of those which thought it not worth notice was the local Dayton newspaper. The general attitude to the flight was one of doubt as to whether it had taken place at all, and that if it had, it was of little significance.

The total cost of the construction of the first flying machine, and the trials, including rail fares and living at Kitty Hawk, was about £200, and was found entirely by the Wrights themselves.

The Wrights were now convinced that the aeroplane would have practical importance, and might have possibilities for mail-deliveries and exploration. They thought that as a military scouting machine it could be used for discovering the enemy's manœuvres. Their first idea was that the new air weapon would be of more service to peace than to war, by making war more difficult, or impossible. The same kind of notion was held subsequently by some of the inventors of the atomic bomb.

The brothers rented a field near Dayton, and began to devote more of their time to aviation, leaving their cycle business more and more in the hands of assistants. During 1904 and 1905, they built improved machines and engines. They solved the problem of tail-spin, which enabled them to make sharp turns. Towards the end of 1905 they circled round their airfield for more than 38 minutes, covering a distance of 24 miles.

There was still remarkably little interest in their flights.

One reason for this was their rigid attention to safety. They refused to fly unless the conditions were entirely to their satisfaction. Consequently, reporters spent fruitless hours waiting for them to perform and then went away in disgust, and never came again. The plane was rarely flown at heights of more than ten or fifteen feet, to reduce the danger of crashes. This skimming along the ground did not look spectacular, and many persons who saw it did not consider it real flying.

While interest in the Wrights' flying increased slowly in America, observers in Europe were alert. Chanute had informed the Aeronautical Society in London about their activities as early as 1902, and through him a member of the Society called on the Wrights at Dayton in that year. The contact was extended, and in 1904, Colonel Capper called to see the Wrights at Dayton on behalf of the British Government. The Wrights were aware that the possession of their patents, and still more, of their unpublished knowledge of aerodynamics, would be of great military value.

At that time, they would probably have been willing to sell their patents and scientific data for ten thousand dollars, and then to have devoted the rest of their lives to private scientific pursuits.

While the discussions with the British were proceeding, the Wrights decided that they should offer their inventions to the United States Government first. They wrote to the War Department in 1905, and received in return a letter in which the President of the Board of Ordnance said that it appeared that their machine had not yet been brought to the stage of practical operation, and that the Board did not make subventions for the experimental development of flying machines.

The Wrights had, of course, been making practical flights for more than one year, and had not asked for any subvention. It appeared that the Board had a stock letter for answering the numerous cranks who made proposals for flying machines, and thought they had disposed of the Wrights as such.

Later in the year, prompted by Chanute, they wrote again to the U.S. War Department, and received a similar reply in the same phrases, based on the same stock letter. Through the intervention of Henry Cabot Lodge, and Theodore Roosevelt, who was then President of the United States, the Wrights were approached in 1907 by the Ordnance Board. They offered to make a first machine for the Board for £20,000. The Board thought this too much.

The brothers had meanwhile had a tremendous reception in Europe, where many war departments began eager negotiations with them. The Ordnance Board began to feel uneasy on hearing this news, and now wrote to the Wrights in Europe expressing interest, but that £20,000 was beyond their budget and would need a special Congressional appropriation.

The French Government followed the British in starting confidential negotiations with the Wrights. These had been kept secret even from many of the leaders of the French Government, yet, after they had been going on for some time, the Wrights' first English visitor appeared again, and casually asked the brothers whether the French mission was still in Dayton.

Great interest in the Wrights had been raised in France by Chanute, who was French by origin. Americans in Paris urged their friends in America to make more serious inquiries about them. One of these was an industrialist named H. M. Weaver, who called to see Orville, and reported that his appearance disarmed all suspicion. He looked more like a poet than an inventor or promotor, and in fact he resembled Edgar Allan Poe. (After early manhood Orville grew a moustache, which increased his resemblance to the poet.) He spoke modestly of his work. As for Wilbur, he looked like a scholar and recluse.

In reply to inquiries, Wilbur mentioned that neither of them was married, for it was beyond the means of each of them to afford both a wife and a flying machine.

Scepticism about the Wrights' achievement persisted, as they would not give any of these important inquirers their fundamental scientific information, nor specially demonstrate their machine in flight. They wished to prevent their inventions from being stolen. They decided that they had better acquire financial representatives who could handle these world-wide governmental inquiries.

Soon after they had made the necessary agreements, the firm's European representative wired that one of the Wrights must come to Europe immediately. Wilbur sailed for Europe in May 1907, and the financial representative went to Euston station to meet him as he came off the boat-train from Liverpool. He saw a thin tallish man coming along the platform, and the flash of genius in his eyes told him at once who he was. Wilbur had only one suitcase, and the agent took him to the Strand to buy some evening dress. It was impossible to be with Wilbur for more than a few moments without seeing that he was not an impostor, and what he said must be believed.

Within a day or two, he went on to Paris, where a newspaperman reported that he spoke about his machine most carefully, and that after each question, his clean-shaven face relapsed into a broad, sphinx-like smile. Orville joined Wilbur in Paris and the brothers proceeded to Berlin, for discusions with the German Government. They returned to America at the end of the year.

By this time, the U.S. War Department was beginning to understand the situation better. The Department advertised for tenders for a specification of an aeroplane which only the Wrights could build. But to their embarrassment, forty-one proposals were received, mostly from cranks. Finally, through the intervention of the President, Theodore Roosevelt, a contract to build a machine for the U.S. Government was made in 1908.

The Wrights decided that Wilbur should go again to Europe, to demonstrate their machine, while Orville should remain in America to make the new machine for the U.S. Government.

Wilbur arrived in France in May 1908, and retrieved his machine, which had lain in cases at the French Customs for about a year. He sought a suitable aerodrome, and found one at the race course at Le Mans, near Paris.

When he opened the cases he found the parts of the machine in a terrible state. Many were broken, and seemed to have been thrown in anyhow. He wrote several very nervous letters to Orville, complaining that the machine had not been properly packed, and that this had made his position very difficult. Wilbur did not speak French, and the French mechanics could not understand him, and were not familiar with the novel mechanisms and parts. Wilbur had to do nearly everything himself. Orville correctly guessed that the cases had been opened at the French Customs, and the contents dumped back in disorder.

After most carefully testing and inspecting every detail, Wilbur prepared for his first flight in France. He always flew in his ordinary grey suit, with a high starched collar, and a cap. His manner inspired confidence, but there was still widespread scepticism. Presently, he climbed into the pilot's seat, and released the launching gear. The plane easily ascended into the air, and made sharp turns under perfect control. The aeronautical enthusiasts saw at once that the machine had qualities far superior to those of any other that had previously been seen.

He at once became the most famous man of the day, and his character and personality increased his popularity. He slept beside his machine in the hangar. He was friendly to journalists, and instead of sending them away, got them to help him with carrying tools and doing odd jobs. They were surprised by the width of his reading and general information. He was willing to talk about everything except aviation and the secrets of the achievement of his brother and himself.

French mechanics, accustomed to wealthy amateurs, were impressed by his working with his own hands, and presented him with a signed testimonial, as from fellow-workmen to a comrade. All the children saluted him in the street with cheerful smiles and 'Bonjour Monsieur Wright'.

Eminent persons went to Le Mans in the hope of being taken for passenger flights. C. S. Rolls, and Baden-Powell were among the first to go over from England to see the machine and fly with him.

In the autumn Wilbur was joined by Orville and his sister. Wilbur warned his sister that she might find it difficult to live on her modest teacher's salary in Ohio, after becoming accustomed to the kind of hospitality which was being given to them in France. They moved to warmer quarters at Pau near the Pyrenees for the winter. King Edward VII motored over from Biarritz to meet them and see them fly. Mr Arthur Balfour and Lord Northcliffe arrived, and helped Wilbur to haul the rope by which the plane was pulled to its launching gear.

Wilbur wrote to his father frequently, recounting his experiences. He told him that he was teaching some enthusiastic young Frenchmen to fly. Regarding one of them, he had serious doubts as to whether he would ever make a good pilot, because he was 'a cigarette fiend'.

The brothers were now being celebrated by the whole world, and it was noticed on every side that their fame did not affect in the least their habitual simplicity and modesty.

After Wilbur had left for France in the spring, Orville had built the machine for the U.S. Government, and demonstrated it in a field only 700 feet wide by 1000 feet long,

THE WRIGHT BROTHERS WITH KING EDWARD VII

At Pau, March 1909

SIR FRANK WHITTLE

Photo Baron

near Washington. From this almost incredibly restricted space, Orville proceeded to make a series of records. He circled the field seventy-one times in a flight of one hour fifteen minutes.

But on the next flight disaster occurred. He had with him Thomas Selfridge, a twenty-six-year-old military officer. After flying for a few minutes, a fault developed, and the machine crashed. It was found afterwards to have been caused by the cracking of a propeller. When Selfridge was taken out of the wreckage, he was dead. Orville appeared to have a fractured leg and four broken ribs. He seemed to recover fairly quickly, but was troubled with severe pains. Not until twelve years later did he learn, after a very thorough X-ray examination, that he had also suffered three fractures of the hip bones, and a dislocation of one of the hips. After his apparent recovery, Orville had joined Wilbur in the autumn in France, but for the rest of his life he had to wear a special waistcoat to support his spine.

When the brothers returned from Europe, they were approached by a young financier named Peterkin, with a proposal for forming an aircraft company. Peterkin was only twenty-four years old, but he had been J. P. Morgan's office-boy at the age of fifteen. He secured the interest of Cornelius Vanderbuilt and other magnates in the Wrights' inventions, and within a month, in 1909, the Wright Company, with Wilbur as President, was established to manufacture their planes. During the first years the company's business was particularly profitable, as there was a big demand for exhibition flights. They won many prizes, and secured payments from various countries for the use of their patents. The British Government paid them £15,000, a handsome sum in those days.

The brothers were now acquiring some wealth, and immediately began to look forward to retirement with sufficient means to pursue their own private scientific researches. But both brothers had to work strenuously to protect their patents. Wilbur went to Europe to take proceedings against several infringers. He became exhausted with this detailed and tedious labour. He fell ill with typhoid fever, and had not the strength to withstand the disease. He died at Dayton on May 30th 1912, at the age of forty-five.

His will was made only ten days before his death. He left £10,000 to each of his elder brothers and his sister, and £200 to his father, for the purchase of any little luxury that he might need. The rest of his fortune he left to Orville, who, he knew, would use it in the same way as they would have done together, if they had both survived to old age.

Bishop Wright noted in his diary that Wilbur had had 'an unfailing intellect, imperturbable temper, great self-reliance and as great modesty'. He noted again the strength of his memory and intellect, his capacity for systemization, and his power of expression in speech and writing, his taciturnity, and imperturbability of temper.

After he had disposed of his own industrial interests in 1915, Orville devoted much of the remaining thirty-three years of his life to the protection of the Wright priority in achieving flight. He husbanded his fortune carefully, and when he died on 3 January 1948, at Dayton, he left an estate of £267,000.

The attention to patents and priority, which had probably hastened Wilbur's end, involved Orville in one of the most extraordinary incidents in the history of science and engineering.

After the repeated and disastrous failures of his aircraft in 1903, Langley had died in 1906, a disappointed man. Some of his scientific friends, and especially his successor at the Smithsonian Institution, convinced themselves that he had made the first piloted machine which could fly under its own power.

In Langley's day, the Secretary of the Smithsonian Institution was regarded as the official head of American science. The fact that the Secretary believed that the power-driven plane was possible had been an important encouragement to the aviation pioneers. The Wrights expressed their deep appreciation of this part of Langley's work for flight. He had helped to strengthen their belief that it was possible.

Langley made extensive researches in aerodynamics which contained some useful results, but also some serious deficiencies. He directed experiments on the construction of many different kinds of engines, and had considerable funds and excellent technical assistance at his disposal. As the Smithsonian Institution is in the centre of Washington, his work received much attention. When the Spanish-American War broke out in 1898, he was invited to devise some kind of flying weapon which might be utilized in the war. He received £10,000 for experimental research. On the basis of his results, he designed a big, piloted aeroplane. A quarter-sized model without a pilot made a sustained flight of one thousand feet over the river Potomac at Washington.

This success raised hopes for the big machine. A five-cylinder radial engine weighing only 207 lb. and developing 54 h.p. was constructed for it in the Institution's workshops. It was a magnificent piece of work, and ten years in front of its time. Langley intended to launch his plane from a high platform on the top of a big barge in the Potomac. But when this was attempted, the machine caught in the launching gear, crumpled up, and fell straight into the river.

Large numbers of journalists had assembled to see the trial. They ridiculed the fiasco, and represented those who attempted flight as lunatics. Langley was deeply upset, and died three years later.

Among the causes of his failure was his lack of gliding experience, which he could not have acquired because of his age. Another cause was his lack of engineering insight. He had not discovered how to apply correctly the results of experiments with models to full-scale machines. And there were even serious deficiencies in his purely scientific research on aerodynamics.

Langley's failure greatly prejudiced aviation both in the public and official mind. It happened in Washington, where all the senators and representatives in the United States were assembled. It was one of the causes of the great difficulties which the Wrights experienced in getting their achievement understood and appreciated.

The startling contrast of the Wrights' success with Langley's failure might have shown to many the extent of their achievement and genius, for Langley was a good scientist. But for a long time this was not so. Conventional scientists felt hurt in their prestige by Langley's failure, and the Wrights' non-publication of their own scientific research seemed to make their achievement appear an accident. When the extent of their private scientific researches became clearer, the academic scientists were still more annoyed, because the non-publication of scientific research was contrary to academic tradition.

Langley's friends and successors began to try to prove that Langley's machine was in fact the first piloted machine 'capable of flight', and that it had been wrecked through irrelevant circumstances, and not through any fundamental fault in the machine itself. They tried to establish Langley's priority as the father of flight, in spite of his fiasco. Langley died before this began. He never made any attempt himself to minimize the Wrights' achievement.

In 1910, the Secretary of the Smithsonian Institution invited the Wrights to send a model of their machine for exhibition in the National Museum as 'one of the most interesting specimens'. Wilbur offered to reconstruct and send the original 1903 machine, whose parts were still at Kitty Hawk. But it became clear that the Secretary did not want it. He was primarily interested in exhibiting Langley's flying machine as the prior invention. The Wrights did not send their machine.

Parallel with these events in scientific circles, the Wrights' industrial rivals were trying to enter the new aircraft industry. They found that they could not evade the Wright patents. They therefore joined forces with the scientists, and supported them in their efforts to disprove the Wrights' priority. Langley's successors at the Smithsonian Institution were approached by these aircraft manufacturers, who suggested that Langley's old plane should be taken out of the museum, put in running order, and its capability of flight demonstrated. This was done in 1914. Some hops of about five seconds' duration were made on a lake, using the machine as a waterplane.

The Smithsonian Institution published reports in which it was said that the trial established that the Langley machine was the 'first aeroplane capable of sustained free flight with a man', and that it was the 'first aeroplane in the history of the world of which this can truthfully be said'.

It gradually became known, however, that the Langley machine had been greatly modified and reconstructed for the trial. Thirty-five substantial features in the design had been changed. In fact, ailerons were added, which were one of the Wright patents. The Smithsonian Institution did not mention most of these changes, especially the fundamental ones.

In 1916, Dr. Alexander Graham Bell, the inventor of the telephone, who was a Regent of the Smithsonian, happened to see the original Wright machine at an exhibition in the Massachusetts Institute of Technology. He asked Orville Wright why it was not in the National Museum. He was astonished when Orville told him that the Smithsonian did not want it.

Meanwhile, the officers of the Science Museum in London learned that the original Wright machine had been stored in a warehouse, and was in danger of fire hazards. They asked that they might have the machine for exhibition. As the American authorities showed no sign of changing their attitude, Orville decided in 1923 to loan the plane to the Science Museum. But before he sent it he raised the matter again with the honorary head of the Smithsonian, the Chief Justice, W. H. Taft, who replied that he had only a nominal position in relation to the Institution's affairs, and had no time to investigate particular matters such as this.

In 1927, the Secretary of the Smithsonian died, and the appointment of a successor seemed to provide the opportunity for a satisfactory resolution of the situation. But Orville found that attempts to evade the issue continued, so he finally sent the plane to the Science Museum in London in 1928, arranging that it should remain there for not less than five years, and permanently unless brought back to the United States within his lifetime.

The departure of the plane hurt American national pride. The people wished to take satisfaction in the American invention of power-driven aeroplanes, and a public demand for the return of the Wright plane arose. Many persons wrote to Orville regretting that he had sent the plane to London. He replied that he believed his action was the only way of correcting the history of the flying machine, which had been perverted by the false statements issued by the Smithsonian. In its campaign to discredit others, the Smithsonian had published scores of false statements, which could be directly disproved from documents. But people had not taken the trouble to examine the evidence. If in these circumstances the machine were placed in any American museum, the national pride would be satisfied without the prior establishment of the historical facts. Nothing further would then be done, and the Smithsonian would continue its propaganda. But if the machine were in a foreign museum this would be a constant reminder of the reason why it was there, 'and after the people and petty jealousies of this day are gone, the historians of the future may examine impartially the evidence and make history accord with it'.

He concluded by commenting that the regret of his correspondents that the old machine should leave America could hardly be as great as his own.

As the years went by, the popular anger at the absence of the Wright plane from the American National Museum grew. There was increasing insistence that it should be brought back, and placed in the leading position of honour.

But Orville would not agree to the return of the machine until the Smithsonian had completely retracted its false statements. Not until 1942 did the Smithsonian finally agree to a full retraction. It then admitted in detail the thirty-five changes which had been made in Langley's machine, and sincerely regretted the acts and assertions which 'may have been misleading or are held to be detrimental to the Wrights'. The hope was expressed that this apology would enable 'Dr. Wright to bring back to America the Kitty Hawk machine to which all the world awards first place'. This would be 'a source of profound and enduring gratification to his countrymen everywhere'.

Orville's long struggle for the establishment of historical truth, in the face of possible national misunderstanding, was a further revelation of the greatness of the Wright character. His inflexible determination on this matter of principle seems to reflect the shadow of old Bishop Wright, who had established in all his family the strict observance of the simple but profound moral verities. By his stand, Orville not only established historical truth, but helped to raise the moral standards and critical awareness of the American nation. This may, perhaps, be regarded as the main achievement of the second half of his life.

Orville now agreed to the return of the plane. But because of the conditions arising out of the Second World War, it was not possible to instal it formally in the National Museum at Washington, until the forty-fifth anniversary of the first flight, on December 17th 1948, nearly a year after Orville had died.

The brothers received many honours, and insisted that these should always be shared. When Wilbur was in France, he said that he could not accept a Legion of Honour award unless it was given to Orville, too. On one ceremonial occasion in Paris, when he was presented with a prize of 20,000 francs, he solemnly divided it into halves in front of the company, handed one half to Orville beside him, and then put the other half in his own pocket.

While Wilbur was alive, he habitually took the lead in action, as was expected of the elder brother. The two men were, however, in different ways, equally strong personalities. Orville was more inspired in the propounding of mechanical ideas; he had more scientific fancy. But he lacked persistence in working his ideas out, and expounding them. He failed to write an adequate account of their life and work, though he survived his brother by thirty-six years. He contributed his full share of the creative initiative during their collaboration, but did not make any aeronautical inventions of great importance after the death of his elder brother.

Wilbur had a greater critical and executive genius. He worked out and developed Orville's ideas as well as his own, and he wrote much, in a fine clear penetrating style, of wide imaginative scope and philosophic range.

Their respective qualities seemed to set fire to each other's genius, and combine in a creative flame which burned new and deep trails for human endeavour. Their work was a marvellous example of economy of thought and resources, and a classic of scientific elegance.

They lived in the mechanical civilization of modern America, and fully inherited its characteristic technical ideas and outlook. But they stood apart from American commercialism, though they were quite competent in handling it. They were in it but not of it.

Their particular religious upbringing was probably one of the main causes of this detachment, which contributed so much to their achievement. Their spiritual background was rather like Faraday's, and their gift of foreseeing the theories and methods of the future on the basis of the work of their own hands, was not unlike his.

Much has been said and written in honour of the Wright brothers, but they more than earned all the great praise that has been, and ever will be, bestowed on them.

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FRANK WHITTLE

(*1907–*)

PROPULSION by jets brings mankind into a new age. The old age of propellers and piston-engines was a mechanization of the bird. The propeller blades beating the air corresponded to the waving of the wings, and the pushing and pulling of the pistons to the articulations of muscles and bones.

Jet propulsion is an advance from the world of the flying animal and its mechanical imitations, to the direct use of inanimate power, like the transition from horse-riding to motor transport.

The man who has started this revolution is Sir Frank Whittle. His engine substituted the jet for the propeller, and began the advance into the new age. The next step will be the abolition of dependence on the air altogether, both for combustion of fuel and lift of wings. But for civilian purposes, this stage still belongs to the future.

Frank Whittle was born at Coventry on June 1st 1907. His father was a mechanic from Lancashire, who had started work at the age of eleven in the cotton mills, and had acquired his skill in the very hard conditions of the nineteenth century. It was significant that he had moved from the centre of the cotton trade, the dominant industry of the nineteenth century, to the centre of the motor trade, the dominant industry of the twentieth. His son Frank belonged both by years and by industrial environment entirely to the twentieth century. His father took a fine photograph of him when he was four years old, proudly holding a toy aeroplane which he had received as a Christmas present. Frank was almost born with flight in his hands. From the beginning his thoughts ran on the air. His father had an inventive mind, and used to spend his spare time at the weekends making drawings of his engineering ideas. There is little doubt that Frank Whittle inherited inventive talent from his father. He became familiar with the instruments of the engineer's drawing-board at a very early age.

By stringent saving, his father managed to collect enough money to purchase a one-man works in Leamington, for making valves and piston rings. Frank began to help him out of school hours from the age of ten, drilling valve stems, and turning parts in a lathe. He was paid for what he did on a piece-work basis.

The first six years of his school-life were spent in local council schools in Coventry and Leamington. To his surprise, he was awarded a scholarship at the age of eleven to the local secondary school, which presently became Leamington College. At eleven the father had gone into the mills, but at that age the son went to a higher school; a striking contrast between the conditions in the two centuries. Whittle believes that if his father had had similar educational opportunities he would have become a distinguished engineer.

He was not particularly successful at his secondary school, because he disliked homework. Instead of doing it thoroughly, he spent his evenings reading with passionate interest books on popular science, and especially aeronautical engineering. Already in his school days he was interested in turbines. He ransacked the shelves of the Leamington Spa public library, and mastered the simpler books on the theory of flight and on practical flying. He became so familiar in his imagination with every detail of the latter that he felt he could climb into an aeroplane and fly right away without any instruction.

He set his heart on joining the Royal Air Force, and applied for acceptance as a boy apprentice in 1922, when he was fifteen. He passed the written examination brilliantly, but was rejected at the medical examination because he was only five feet high. He was a small, wiry boy who liked climbing, had plenty of nerve, and a strong sense of balance; but these qualities were not enough.

He was extremely disappointed and pleaded that his case should be reconsidered, but the authorities would not depart from their rules. A sympathetic drill sergeant was impressed by his intense distress, and advised him to follow a special diet and system of exercises, which he drew up for him. Within six months, Whittle had added three inches both to his height and his chest measurement, which demonstrates how much there was to learn about diet and exercise for schoolboys even so recently as 1922. With his added inches, he applied again for an apprenticeship, but was now told that having once been rejected he could not be subsequently accepted, even if he had since come up to size. He was desperately cast down again. Then he decided to apply yet once more, after a suitable interval, without mentioning that he had previously been a candidate, and was duly accepted. Thus Whittle ultimately had to join the Air Force almost under false pretences.

He entered the apprentices' school at Cranwell in 1923. He did not like the barrack-room life, but found that he was being given a very good training as an aircraft mechanic. The severe course produced respect but not enthusiasm. He found, however, that the apprentices' Model Aircraft Society provided a splendid medium for the expression of his flyer's yearnings. He was at once absorbed in designing and making model aircraft. He became the leader of a team which built a magnificent ten-foot model driven by a two-stroke petrol engine. It was to have been flown before the Under-Secretary of State for Air on the school's passing-out day, but at the last moment the sparking-plug of the engine, which was the only part of the whole machine that they had not made themselves, failed. Whittle has remarked that possibly his strong prejudice against piston engines began with that event.

The first five apprentices in the final placing at the end of the course were recommended for cadetship in the officers' college. Whittle was sixth, owing his high place largely to his achievements in model-making. Even so, he would not have been recommended if it had not happened that the top boy proved to be medically unfit. Whittle only just scraped into the cadets' ranks.

He was overwhelmed with joy at this good fortune, for admission as a cadet meant that he would become a pilot, and achieve his ambition of flying. He was conscious, too, of a very big rise in the social scale, for the gap between apprentices and cadets was wide.

Whittle entered the cadets' college, which was also at Cranwell, in 1926. Though this institution was still very young, it had already developed many deep-rooted customs, some of which resembled those of Eton or Oxford. The cadets who had just entered the college drilled for the first two weeks in dark lounge suits and bowler hats, preparatory to receiving their uniform. For those who had previously been apprentices and had for years worn the lower rank's uniform, this peculiar change of dress seemed to emphasize the difference between their new and old status.

The course contained excellent instruction over a broad syllabus in science, the humanities and workshop practice. The latter was of a wider but more superficial character than that given to the apprentices who were being trained to be mechanics. The subject which all regarded as by far the most important was practical instruction in flying.

Whittle tried to continue making model aircraft, but he found that his time was too fully occupied, and that his interest in it declined now that he was engaged in the real thing. His youthful passion for model-making had in part been a sublimation of the desire to fly.

During his flying training he temporarily lost his confidence, due, he thought, to bullying by an instructor. After tests of aptitude and wise psychological advice, he became an extremely adventurous pilot. He was officially described as over-confident, apt to play to the gallery and fly too low. He became a considerable acrobatic flyer, and was the first cadet to perform the manœuvre known as the 'bunt'. This consists of flying the first half of a loop with the pilot on the outside of the arc, which is much more difficult than flying on the inside.

The cadets were expected to write an essay or thesis on some scientific subject during each of their four terms of residence. In his last term, in 1928, Whittle decided to write on 'Future Developments in Aircraft Design'. This was the first clear starting point of his future achievements.

At that time, the top speed of fighter aircraft was about 150 m.p.h. He looked forward to the future when aircraft speeds would be 500 m.p.h., and analysed the conditions under which this might be possible. He concluded that if planes were to have any considerable range at such speeds then they would have to fly very high. Otherwise, the dense air near sea-level would offer so much resistance that immense quantities of power would be consumed in overcoming it. The plane would not be able to carry enough fuel to keep up this power for a long flight. Unfortunately, however, while thinness of the air is an advantage for the reduction of resistance, it is a disadvantage in another way. If the engine receives air directly at low pressure it loses much of its power, since the power produced depends on the quantity of air consumed in the combustion of the fuel. If the engine cannot consume air at a great rate, it cannot produce great power.

Thus a combustion engine utilizing air cannot produce great power at great altitudes unless the air is sucked from the atmosphere, compressed, and delivered to the engine in a dense state so that a large mass of it is put into the engine very quickly.

Ordinary piston-engines are for this reason provided with super-chargers for flying at high altitudes. The super-charger is merely a form of compressor for compressing the rare air and feeding the engine with dense air, such as it would receive without a compressor at sea-level. The super-charger thereby enables the engine to run at high altitude under conditions similar to those near sea-level, and thus not lose power through the rarity of the air at great heights.

Whittle considered what kinds of engines might be suitable for such high-speed, high-altitude flying. It seemed to him that piston-engines would become less and less suitable as the speeds and heights became greater and greater, so he examined the possibilities of other types of propulsion. Among these were the ordinary kind of rocket propulsion, in which a jet of gas is projected from a chamber, and the plane as a whole goes forward by the force of reaction. He examined also the possibility of substituting a gas-turbine for the piston-engine for driving the aeroplane propeller. He had not yet thought of his own system. He was twenty-one years old when he produced this thesis.

He passed out of the college in 1928, gaining the second place, and was awarded a prize for his work on aeronautical sciences.

He was posted as a pilot to a fighter squadron later in the same year, and became engaged to Dorothy Mary Lee, an old friend who lived in Coventry. They were married in 1930, and now have two sons.

Whittle very much enjoyed the life in the small intimate community of fighter-pilots, especially after the previous five years of school and college. In 1929 he was sent to a course for flying instructors at Wittering, to qualify as a teacher of flying. He received further valuable lectures, in addition to the practical flying, and he continued to think about the problem of high-speed, high-altitude flight. He calculated the possibilities of a jet-propulsion system in which air was compressed by a fan driven by a piston-engine and then heated by the burning of fuel before being expanded as a propelling jet. He concluded from his calculations that this system did not offer any significant advance over the piston-engine propeller aeroplane. He learned later that it had already been patented in 1917. The Italian Caproni company produced a jet-aeroplane with an engine of this type in 1940, but did not pursue its development.

While Whittle was pondering on the piston-engine jet scheme in the latter part of 1929, he suddenly had the idea of substituting a gas turbine for the piston-engine for compressing the air. This offered the possibility of a brilliant simplification of the arrangement. Why not use the exhaust from the compressor turbine as a jet for propelling the plane, and cut the propeller out altogether?

He arrived at this idea by transferring the main attention from the shaft to the exhaust of the turbine, from a rotating shaft to a stream of gas.

It seems an extraordinary thing that there should be two such entirely different ways of drawing power from the same engine, one through the shaft, and the other through the exhaust. The mind of engineers had been running for generations on the turbine shaft as the means of delivery of turbine-power. A tremendous effort of the imagination was therefore necessary to escape from this conventional routine of thought, and to see the exhaust, and not the shaft, as the business-end, as it were, of the turbine.

This was Whittle's fundamental idea. But how was it to be carried out? Why not compress the rare air in a compressor driven by a gas-turbine, and then heat the compressed air by burning with fuel in order to produce a swiftly-moving stream of very hot gas? Some of the energy of motion of the stream of gas could be used for driving the turbine, and the rest could be used in a powerful jet issuing from the exhaust which would propel the plane forward as in an ordinary rocket. The turbo-jet engine was in fact a device for producing a powerful sustained jet of hot gases from the rear of the plane.

Such an arrangement could, in principle, be reduced to a big horizontal pipe, into which air rushes or is sucked at the front end. Along the axis of the pipe would be a single steel shaft, with a wheel at the front end which would operate like the fan of a vacuum cleaner, and another wheel at the back end which would act as a turbine. In principle a turbine is nothing more than a windmill blown round by a swift stream of gas. The whole moving part of the engine would consist merely of the single shaft with these two wheels firmly fixed to it. The principle was extraordinarily simple.

The big-pipe form of the engine fitted very conveniently into the shape of the aeroplane structure. In single-engine machines it could be combined with the fuselage.

Whittle's preliminary calculations showed that such a design had most promising possibilities. But they also showed that the running of an engine of this type would be confronted with at least three major practical difficulties. Firstly, the compressor would have to be very much more powerful than existing super-chargers. Secondly, the chambers in which the burning of the compressed air and fuel occurred would have to be much more resistant to heat than the walls of any kind of engine-furnace then in use. Thirdly, the metal of the turbine blades would have to be more resistant to the combined effects of high temperature and extreme stress than the best materials then known.

In the midst of his busy training as an instructor in flying, Whittle found his imagination seething with this beautiful but tantalizing engineering dream. The turbo-jet engine would be an enormous advance on the piston-engine—if it could be made.

He discussed his idea with all who were interested. Among the subjects of his R.A.F. course at Wittering was the technique of flying by instruments, without being able to see the ground. His teacher for this subject was W. E. P. Johnson, who was a qualified patent agent in civilian life. Johnson at once appreciated Whittle's idea with a professional eye, and had it brought to the notice of the commandant, who sympathetically forwarded it to the Air Ministry for consideration. Within a very short time, the twenty-two-year-old pilot, who was a flying man without any academic qualifications in engineering, was seen by the leading gas-turbine experts in the Government service, who explained that the lack of materials which would withstand the required combination of very high temperatures and extreme stresses made the invention at present impracticable.

The Air Ministry accordingly informed him that they would not be able to pursue his idea. In spite of this, however, Johnson urged Whittle to apply for a patent, and assisted him in drawing up a specification. This was filed on January 16th 1930.

Whittle, as a serving officer, notified the Air Ministry of his action, but the Ministry informed him that they had no official interest in the patent. Accordingly, it was not kept secret, but duly published, and made freely available to all the world, after it was finally granted in 1931.

Meanwhile, Whittle qualified as a flying instructor, and found the work more interesting than he had expected. It was necessary to strengthen the pupils' confidence, and help them to gain a correct balance of enterprise and caution. This required a study of the different temperaments of the various pupils, so that each could be helped in the appropriate way.

Whittle gave exhibitions of crazy flying at the R.A.F. Display at Hendon, engaging in mock collisions, and hopping at a height of two or three feet above the ground, intentionally making all the mistakes of the novice.

While Whittle was teaching pupils and giving exhibitions of crazy flying, he pursued the development of his invention with unabating zest. Through his friend Johnson he visited various firms, and at the end of 1930 discussed it with the chief turbine engineers of the British Thomson-Houston Company at Rugby. They listened to the young pilot with much patience, but told him that the development of an engine of this kind would cost at least £60,000, and B.T.H. could not afford such an expenditure for this project. The industrial depression was then at its worst. Whittle thought that engine development would have been a particularly good thing to pursue during such a period, when many able men had little to do.

At the end of 1930 Whittle was posted as an experimental test pilot at Felixstowe. One of his chief tasks was to test various catapult devices. These were designed to raise the speed of the aircraft to be launched, from rest to about 60 m.p.h., in a distance of about sixty feet. Before the device was tested at sea, experimental set-ups were arranged on the ground. Usually, a sheep was strapped in the seat, and the effect on it of being thrown by catapult noted before the test pilot was invited to take its place.

In the last of five series of catapult tests, Whittle was launched from an aircraft carrier in the Solent, and found his machine almost out of control, as if the tail-plane were being held down. He glanced round and saw a body lying on it, and suddenly realized that his companion Flight Lieutenant F. Kirk, had been jerked out of the seat behind him. He had caught a wire as he fell, and had managed to scramble full-length on to the tail-plane. The captain of a German liner, seeing that the almost uncontrollable plane was flying directly at his ship, swung her around at the risk of going aground.

While Whittle was trembling with excitement, his companion unconcernedly crawled back in mid-air into his seat, and asked him what he was worrying about.

At the conclusion of the tests, Whittle was officially commended for making forty-seven catapult launches, nine of them in one day. His airmanship had inspired confidence in everyone, and his skill and intensity of work had enabled conclusive results to be obtained very quickly.

While explaining the idea of his engine, and making important and dangerous experiments on catapult launching, he became a father. His first son was born in May 1931. This added to his anxieties, for at that time officers of his rank did not become entitled to a marriage allowance until they were thirty years of age, and he was as yet only twenty-four.

The variety of experiments at Felixstowe inspired him to many different kinds of inventive ideas. He devised an entirely new form of catapult, and a new method of loading bombs based on catapult mechanisms. He invented a 'flying bolas' for bringing down aircraft, on the principle of the South American natives' weapon consisting of a string with weights at the two ends, and one in the middle. When the bolas is thrown at an enemy it winds round him, ties him up, and brings him down.

He devised a novel method of representing the field of fire from the various guns on a flying boat on a single diagram. He designed an enclosed gun-turret, a single-fluke (or prong) anchor for anchoring flying boats, and various other devices. Only one of these, the fire-diagram, was officially adopted.

In the midst of all this, he talked to anyone who would listen about his engine, visiting more firms, and buttonholing representatives who happened to come to the station. One of his fellow-officers, R. Dudley Williams, who had been a cadet with him at the R.A.F. college, was deeply interested, and tried to raise funds to extend his patent to America and other foreign countries, but without success.

Whittle saw that he would have to convince the experts that it was possible to design far more powerful compressors before he would be able to get them to consider his whole engine seriously. He therefore wrote and published a paper on the subject in the journal of the Royal Aeronautical Society. He still had not received any special engineering training.

He was, however, approaching the completion of his first four years as a general flying officer, and was now expected to specialize in some particular branch. He chose engineering, and in the summer of 1932 was posted to take the two years' Engineering Course at Henlow. In the preliminary examination for new students, he obtained an average of 98 per cent in all papers. Because of this remarkable performance, he was allowed to take the two years' course in eighteen months, and he began to realize for the first time how much engineering knowledge he had almost unconsciously acquired through following his bent.

On the strength of his work in the Henlow course, Whittle applied to the Air Ministry to be sent to Cambridge to read for an engineering degree. The Ministry had only recently discontinued a scheme under which one or two of the most outstanding young Air Force engineers were sent to Cambridge for an academic training. The Ministry agreed to revive the scheme for Whittle's particular case. He was posted to Cambridge in 1934 as a serving officer, to study for an engineering degree, which he was expected to secure in two years, instead of the normal three, because of his already considerable engineering training. He was also to act as a tutor to the Cambridge University Air Squadron.

Whittle was twenty-seven years old, and a married man, when he went to Cambridge. He was attached to Peterhouse. Because of his experience, he found much of the theoretical teaching in the Cambridge engineering course of intense interest. Many things which seemed to the young students straight from school to be only of academic interest, contained the explanation of peculiar phenomena which he had noticed, but had not hitherto understood. He felt that there was much to be said for students having a considerable practical experience before taking thorough theoretical courses such as those at Cambridge.

Whittle's experience with his various inventions had convinced him that there was generally little chance that a serving officer's inventions would be adopted by the Air Ministry. He decided not to patent future inventions except on the initiative of the Air Ministry. He felt that a young married officer without a marriage allowance could not afford to spend even the small sum required. In spite of his incessant discussion of the engine, he began to feel that it was perhaps in front of its time.

The Air Ministry informed him that the renewal of his patent would become due in January 1935, and that it had no intention of paying the £5 required out of official funds. His despondency at the prospects of the engine, and increasing financial stringency through the birth of a second son and the attendant medical expenses, led him to conclude that he could not afford the £5 for renewal, so he allowed his master patent to lapse.

Three months later, he received a letter from his old Cranwell and Felixstowe friend, R. Dudley Williams, saying that he had met an important engineer who wanted to consider developing the engine. Williams and his partner J. C. B. Tinling came to Cambridge, and spent a long Sunday afternoon at Whittle's house in Trumpington, discussing what they might do. They agreed to form a partnership, Williams and Tinling to act as Whittle's agents. Whittle insisted that whatever they did, they were not to offer the invention to one of the aircraft firms.

They then met Williams' important engineering acquaintance, M. L. Bransom. They were relieved to find that Bransom did not propose any connection with the existing aircraft firms, but suggested that they should seek the financial support of O. T. Falk & Partners, the investment bankers. It was part of the policy of this firm to seek scientific inventions worth developing. A member of the firm, L. L. Whyte, who had studied under Rutherford at Cambridge and Einstein in Berlin, and had a special interest in the philosophy of experimental and theoretical physics, attended to this side of their business. Probably no other banker of the day had such qualifications for appreciating an advanced scientific invention. Whyte at once perceived that Whittle had the qualities of enthusiasm and scientific ability which might make him one of the greatest inventive engineers of the century.

While Whittle was following the normal university degree course, and pursuing research on aerodynamics under Professor Melvill Jones, he held numerous meetings with his partners and L. L. Whyte. Finally an agreement was made, to which the President of the Air Council was a party, that a company should be formed to exploit the turbo-jet engine. Whittle was to assign his surviving patents to it, and O. T. Falk & Partners were to provide the funds. The Air Ministry insisted that Whittle should not allow his work for the company to conflict with his official duties, and he was not to devote more than six hours a week to the company's work. The Ministry thereby made it quite clear that Whittle's work on the engine did not come within his official duties.

The company was incorporated in March 1936, under the title Power Jets Limited, with L. L. Whyte as chairman. A sum of £2,000 was produced for the initial working capital. The construction of the first turbo-jet engine began even before the incorporation of the company. It was in the turbine works of the British Thomson-Houston Company at Rugby, according to Whittle's designs.

In addition to frequent visits to Rugby, Whittle had to call at many other engineering works in connection with various aspects of the job. One firm was in Edinburgh, so he usually flew there, in order to keep up the regulation number of flying hours required of a serving officer.

As he struggled with all these problems, the date of his Cambridge degree examination approached. He devoted the last five weeks before the examination to intense study, catching-up on subjects which he had neglected because of his other preoccupations. He had set his heart on gaining a first-class degree in engineering, and did so, but at a cost to his health. His intense efforts caused signs of nervous over-strain.

After he had graduated, the Cambridge authorities recommended the Air Ministry to grant him a year for post-graduate research. The Ministry agreed, so he became virtually free to give the whole of his time to the development of the engine.

He had intended to build it part by part, testing each part exhaustively until it functioned perfectly. But this procedure could not be followed because of expense. The plant for testing the compressor alone would have cost £27,000, whereas only a few thousand pounds were available for the construction of the whole engine. He therefore set out to make a whole engine of novel type, developing some thousand horse-power, without exhaustive preliminary research on the various components.

The shortage of money and resources caused him to take tremendous risks. He designed the engine as best he could, put it together, and then hoped for the best. By the end of 1936 the construction of the first engine was nearly finished. It had cost only £3,000.

It was set on a truck in the British Thomson-Houston works, and prepared for its first trial run, on April 12th 1937. After starting the engine at slow speed, Whittle opened the fuel valve. The engine gradually gathered speed for a few moments, and then began to race faster and faster, until it was shrieking like an air-raid siren, and parts of the metal casing of the combustion chamber glowed with a bright red heat.

The experienced British Thomson-Houston turbine engineers saw that the engine was out of control, and knew the danger. When the engine is running very fast, the tips of the turbine blades travel almost as fast as rifle bullets. Hence, if the machine flies to pieces, the equivalent of a hail of rifle bullets spreads in many directions. Besides the flying metal, the fuel is liable to explode.

The experienced men took to their heels, running like hares, or diving into the nearest cover. Whittle stood by, trying to throttle the engine down. It took no notice of him, but gradually slowed down of itself. He was very much frightened.

In a second test, the same racing occurred again, accompanied by great flames which danced and roared in the air over the engine. The engineers disappeared even more quickly than they had done before. As Whittle has put it, in these early days the persons in the vicinity did more running than the engine.

While he was sitting in the lounge of his hotel after these experiences, Whittle was seized from time to time with fits of uncontrollable laughter, no doubt a form of hysterical reaction after nervous tension.

It was discovered that the racing of the engine was due to a pool of fuel at the bottom of the combustion chamber. This accumulated, and then suddenly fired, and nothing could be done until the pool was burnt up.

These serious risks had to be taken because there was no money for adequate preliminary experiments. They were so short of funds that they could not replace damaged parts of the engine. When a bit came off a turbine blade, an equivalent bit was taken off the blade on the opposite side of the wheel, to balance with the damaged part.

Perhaps Whittle would never have had the nerve to take such risks if he had not had the training of a test-pilot. He always expressed his deepest loyalty and gratitude to the Royal Air Force. He remarked that of his first twenty years in that service, no less than ten were devoted to engineering training. Besides giving him the opportunity to learn, the R.A.F. had also taught him to know what was wanted. When he began to conceive his first engine, he naturally designed it as an airman. He made it far lighter than the non-flying engineer would have done, and he always had in mind the qualities a pilot desires in an engine.

As his experiments proceeded, he began to realize more and more that the gas-turbine had been dismissed as impracticable because the demand for it had not been sufficiently insistent. There were no suitable materials for combustion chambers and turbine blades not because they were impossible, but because they had not been sought for with sufficient determination.

Once the engine was in being, and its possibilities, as well as its weaknesses, were evident, more strenuous efforts were made to produce sufficiently good materials, with ultimate success.

Now that Whittle had made an engine which would work, if only very fitfully, more attempts were made to secure increased financial support. His most influential supporter in official circles was Sir Henry Tizard, then chairman of the Aeronautical Research Committee. He wrote in June 1937 that he considered that there was nothing inherently unsound in his ideas. He thought it highly probable that if he received the necessary financial support and encouragement he would succeed in producing a new type of engine for aircraft. Some kind of turbine was almost certainly necessary to produce the very high powers that would be needed in the future, and the fact that such an engine would run on heavy oil, and would not necessarily need special fuels, was of great military and commercial importance. He had a very high opinion of Whittle's enthusiasm and ability. The combination of such qualities with intimate practical experience was rare, and he deserved the utmost encouragement. Tizard thought that a large financial expenditure would be necessary before final success was achieved, and he hoped that the financing would be private, as that would prevent knowledge of what was being done from becoming too widely known.

In spite of such commendation as this, increase in financial support from private and official sources remained very tardy. The monthly bills were of the order of about £150, and when they rose to £400 in one month, serious concern was felt in Power Jets.

The minute size of the original expenditures on the invention of the turbo-jet engine is astounding. From the beginning to the completion of the first successful flight, the total expenditure was only about £100,000. This was the cost of a revolution in aeronautics. While the money for financing this fundamental innovation was secured only with much difficulty, the subsequent expenditures on development of mere varieties of the new invention became enormous. According to evidence before the Committee of Public Acounts, the cost of development of the Rolls Royce Avon jet engine, one of the many descendants of Whittle's engine, was about £22,000,000. The contrast between the sums available for original invention, and for the exploitation of an engine already known to be practical, is very striking.

But to return to the early days; after much consideration the Air Ministry made a contract with Power Jets, to continue tests with the engine for a fee of £1,900. This precipitated a crisis, for the terms of the contract brought the work under the Official Secrets Act, which increased the difficulty of obtaining additional private finance, for investors objected to putting money into developments which could not be revealed to them.

By June 1938 the total sum spent directly on the engine was still not more than £9,000.

Besides financial worries, the nature of the work caused irritations. The danger and noise of the engine had produced a good deal of disturbance in the Rugby works, so an old foundry at Lutterworth, fourteen miles away, was secured and converted into a works laboratory. A new series of tests was undertaken for the Air Ministry, at a cost of £6,000.

A few old sticks were bought to furnish the ancient building, which was beside a railway line. Whittle engaged night watchmen, a secretary and a dog. The establishment became known in aviation circles as "The Cherry Orchard", because of the apparently inconsequential atmosphere. Visitors observed that at one moment a boy brought in a cup of tea. At the next, someone jumped up and took a pot shot with a rifle at a rabbit through an open window. Then somebody else rushed in and shouted 'Rocking Blotters', intimating that a particular item of luxury had just been successfully obtained.

The Air Ministry, which had had Whittle posted for these special duties, became disturbed by what it conceived to be his slow progress, and intimated that he might have to return to service unless results were obtained more quickly. He improvised more tests, and by June 1939 had run the engine at 16,000 r.p.m. But the problem of burning the fuel steadily was still unsolved. There were great difficulties with the combustion chamber.

In contrast with his slow progress on the combustion side, Whittle was more than successful in his development of turbine design. While calculating the shape of the blades, he was astonished to find that he had arrived at a form substantially different from that traditionally used in steam-turbines. He found that the blades should be twisted twice as much as was customary in steam-turbine practice. He had obtained his result by treating his blades on aerodynamical principles, as if they were aeroplane wings moving through hot gas. This discovery enabled him to make an important improvement in the design of steam- as well as gas-turbines.

The incident is a striking parallel to the Wright brothers' design of aeroplane propellers. Just as they designed propellers as if they were rotating aeroplane wings, so Whittle designed turbine blades on the same principle.

Whittle began to feel that lack of experience and tradition could have its advantages. The power-plant engineers had spent their lives in designing huge expensive machines. Because of this one of their main preoccupations was to save manufacturing costs. Their machines were stationary, and operated under stable conditions. Whittle looked at his engines as a pilot. They had to be light and strong, and run efficiently under variable conditions, in the high temperatures of the tropics, or at the low temperatures and pressures of the upper atmosphere. They had to be swiftly responsive to the pilot's changing needs. As an airman he saw his problems in terms of swirling air and motion, and naturally approached them through the ideas of aerodynamics. He owed his success in turbine-blade design to his use of modern vortex theory, whereas the steam-turbine engineers were using older ideas of fluid flow. It did not seem worth while to them to master the highly mathematical modern aerodynamics in the hope of making some small improvement, the economic equivalent of which might be made in a much easier way by elimination of some redundant operation in the manufacturing process.

So Whittle was beset on all sides by problems. The problems of original invention, the fears of private investors that they might lose their prospective profits, the fears of Government officials that great private profits might be made out of the invention (in spite of the fact that almost the whole of the huge profits of the existing private aircraft firms were made out of vast Government orders), and the conflict of the new tradition of aeronautical engineering with the old tradition of steam-power engineering.

With all these difficulties, he suffered from increasing ill health. He was troubled with chronic eczema of the ears, which began in 1938. He had bad attacks of indigestion, and severe headaches, which he felt affected his judgment. His illness, though not quite of the same kind as James Watt's, seems also to have been of a nervous nature, and connected with intense mental activity.

The Air Ministry began to take a more positive interest in the engine after the promising tests during the early months of 1939. This was largely due to Sir Henry Tizard's influence. The increasing international tension made scientific and technical preparedness absolutely vital to the country's existence. It was due to Sir Henry more than any other man that in various directions Britain proved to be far better prepared in advanced scientific weapons than had been expected. He strenuously supported the research and development of Whittle's engine as one of a series of possibly decisive scientific weapons.

While the planners of military science were backing Whittle more and more, the Royal Air Force was increasingly feeling the shortage of flying officers. There was a tug between the scientific side and the service side for Whittle, and fortunately it was decided that he should devote himself entirely to the development of the engine.

On the strength of the previous tests, Whittle began in July 1939 the design of a turbo-jet engine for trial flights in an experimental aeroplane. The Gloster Aircraft Company was engaged to design the plane.

Whittle was told that if war broke out, he would be expected to continue work on the new engine and plane. Consequently, when the war began he and the small Power Jets group continued their work, though official quarters did not seem to consider it very urgent.

Whittle received the impression that various groups, civil servants, aircraft manufacturers, and others did not consider that Power Jets was the correct organization for developing the engine at this stage. So far, much of the work had been done by B.T.H. engineers under Whittle's direction. In the early months of the war, however, Power Jets began to form the nucleus of a research team. Whyte, Johnson and Tinling now devoted the whole of their time to the company, as a form of national service. A number of first-class young engineers, without much experience in other directions, so that they had not yet got into any groove, were engaged. By January 1940, the total staff was about twenty-five.

Lord Tedder, who was the Director-General of Research and Development at the Air Ministry, came to see the engine, and described it as a really fascinating and impressive job.

Whittle was dissatisfied with the way in which the B.T.H. Company was carrying out the engineering construction of the engine, so he got in touch with the Rover Company. He was surprised to find that this initiative was not encouraged by the Air Ministry, and on inquiry was told that perhaps there might be other companies which would be more suitable for the job. He incidentally received the impression that the supersession of his company must have been discussed, and that there was a danger that Power Jets might be swallowed up by one of the big aircraft companies.

He had feared such a development from the beginning. He had intended the Power Jets Company not only to develop the invention, but to produce it. He was not interested merely in inventing engines as a branch of pure research. He considered that the development and the production should go together. He believed that the making of engines for actual use was the inspiration of invention itself, and the necessary spur to development. He had intended Power Jets, after having invented the new industry, to remain at the head of it, guiding research, development and production all together.

He protested at the suggestion that his invention, now that it was becoming practical, should be taken from the control of Power Jets. Tedder assured him that the Air Ministry would 'not allow the parents to be robbed of their child'.

However, in March 1940, the Air Ministry decided to give contracts for the production of engines to the Rover firm, while the Power Jets organization was to be merely a research and development organization. It was argued that Power Jets had no experience of production technique. Thus, those who had done the fundamental invention and research were to be removed from the guidance of the new industry. As they were not to have the opportunity of making the new engines, their original financial supporters would not be able to profit from their foresight.

The Rover Company, which was supposed to work to Whittle's designs, tried to improve on them without consulting him. Its progress was unsatisfactory.

Meanwhile, big advances were made in the development of the engine. The burning of the fuel in the combustion chambers had long been one of the most unsatisfactory features. Sometimes it proceeded like a series of small explosions, and the walls of the chamber became very unevenly heated.

The practical solution of the combustion problem depended ultimately on the realization that, once again, it was primarily aerodynamical. It was conditioned by the character of the flow of gases inside the chambers and tubes. In fact, the aerodynamical properties of the inside of the engine proved to be just as important as those of the outside of the plane. A model of a combustion chamber was made in transparent plastic, with tufts of fibre fixed at various points inside to reveal the direction of currents in air flowing through it. Decisive help was received from the combustion engineers of the Shell Petroleum Company in finally arriving at a satisfactory design.

Up to this time, in the autumn of 1940, Whittle was still doing all his fundamental work on the single original engine, which by now was little better than a collection of patched-up scrap. He did not receive his second engine until December 1940.

While he struggled with his own fundamental problems, civil servants, and big firms, the general war situation deteriorated very seriously. The country had become isolated. As a service man, he was particularly worried by the military danger. He feared raids by German parachutists on the secrets of Power Jets at Lutterworth. He could see Coventry from his house, and became almost beside himself as he saw large parts of his native city burning in the big air raids. The frustrations in the development of his own secret weapon, which if ready could have been used against the raiders with such devastating effect, strained his nerves more and more. Coventry went up in flames while civil servants and businessmen manœuvred for control of the post-war aircraft industry.

However, the tense national situation did force progress. Power Jets' staff expanded to about 134 by the end of 1940. With success in sight, a new source of tribulation arose. Numerous eminent persons now came to inspect the engine. Whittle, who held the junior rank of Wing Commander had to demonstrate his invention to Air Chief Marshal Dowding, who had shortly before become the renowned victor of the Battle of Britain.

When the engine had been started, the noise drowned Whittle's voice, and Dowding misunderstood an explanation given to him. He started towards the engine, and before he could be stopped, he was knocked sideways by the blast of the jet, and his brass hat was sent rolling across the grass. The engine was shut down, but Whittle was so horrified that he could not speak. Dowding recovered himself, and then asked Whittle somewhat tersely whether he was going to show him something. Whittle dumbly led him into the test house.

By this time, the Air Ministry had boldly engaged many firms on different parts of the jet-engine, though no plane had yet been flown. But by May 1941, the Gloster plane with the jet-engine was ready for flight trials. These were performed at Cranwell, which had had such important early memories for Whittle, by the chief Gloster test-pilot, P. E. G. Sayer. He started the engine with ease, took off, and completed a flight of seventeen minutes, with perfect control.

Thus thirteen years of invention and development culminated in success at last, and aviation development passed into a new stage. The historic machine E.28 is now housed in the Science Museum at South Kensington.

In the early flights with the E.28 it achieved 370 m.p.h., which was faster than the current Spitfire. It proved to be faster than had been calculated, which never happened with piston-engine planes. This was because of the improvement of the stream-line flow of the air over the surfaces of the plane owing to the action of the jet. This had not been allowed for in the design calculations. Maintenance men were astounded when no routine inspection of the engine was necessary after flight. The Power Jet engineers could tell the condition of the engine from its note, and whether or not it needed attention.

The successful flights raised intense interest in the engine, and also increased the struggle over the control of policy. L. L. Whyte resigned from the chairmanship of Power Jets on July 4th 1941, after having nursed the financing of the development from the beginning. Whittle took over the chairmanship. His dissatisfaction with the Rover Company mounted steadily, and the Rolls Royce and de Havilland companies entered the field.

Whittle met the redoubtable Lord Hives, the head of the

Rolls Royce Company. Lord Hives told him that Rolls Royce wished to build their own version of a Whittle engine, not in order to compete with Power Jets, but to contribute to the national effort. He desired Whittle to regard their offer as an extension of his existing facilities for development, both in technical assistance and production.

Whittle welcomed this offer. He said that he had long felt that Rolls Royce were the only people with a sufficiently competent technical staff to carry out such an undertaking. Whittle explained that they had been chary of such offers in the past, as some firms had entered into undertakings which were in his opinion much beyond their technical capabilities, and this had tended to bring the whole development into disrepute.

It was agreed that Rolls Royce should make a number of engines to Power Jets' designs. Presently, however, Lord Hives informed Whittle that he thought it essential that the two firms should be financially connected. Rolls Royce realized that at the end of the war they would be left with a glut of piston-engines, and wished to have a new engine ready which would render the piston-engine obsolete, and create a new market for the firm.

Many months passed before these very interesting talks led to any arrangements. It appeared that both men had supposed that the next move lay with the other. It proved to be a tragic misunderstanding, for the opportunity for a collaboration between Rolls Royce and Whittle on appropriate terms never recurred.

Whittle, unlike Watt, never found his Boulton. Perhaps he was nearest to this in his first discussions with Hives. But perhaps no Boulton could exist under present conditions, and it was not in Hives' power to be a Boulton.

Power Jets received the sanction to construct a handsome new works at Government expense, at Whetstone, near Leicester. It was sufficiently equipped to make experimental engines, and contained 80,000 square feet of workshops.

By the end of December 1942 proposals had been made that the Rolls Royce Company should take over the Rover factory at Barnoldswick, which was equipped for producing engines, while the Whetstone establishment should continue to undertake the fundamental research and development. Within a short time the superb Rolls Royce technique made a dramatic improvement in the production of jet-engines at Barnoldswick, and started the Rolls Royce development of turbo-jet engines which has had such striking results.

The technical collaboration between Rolls Royce and Power Jets was very cordial, but the final relationship was still unsettled. Lord Hives indicated that Rolls Royce intended to become the leaders of jet propulsion. Whittle feared that his guidance of the future of the jet-engine would ultimately be discarded. His health deteriorated still further. He was troubled by irritability, insomnia, and other nervous manifestations. It was arranged that he should take a three months' War Course at the R.A.F. Staff College, to give him a change of occupation. He found that it was by no means a holiday.

His absence was not beneficial either to the problem of the relations between Power Jets and Rolls Royce, nor to the morale of the Whetstone research and development establishment.

Meanwhile, before Pearl Harbour, details of Whittle's engine had been sent to the United States. They became the starting point of the American development of the turbo-jet engine. At the end of 1943, the Americans pressed for the publication of Whittle's achievement. He was appointed a C.B.E in January 1944, and the first description of his engine was given to the Press. He was quite overwhelmed and embarrassed by the publicity after the years of secrecy. He received a huge mail, and was recognized everywhere. He could no longer travel in trains for fear of being buttonholed. He was agonized by the same questions being put to him over and over again, and he felt the publicity had been premature.

It was subsequently discovered that there had been a great increase in turbo-jet development in Germany after the announcement. Post-war inquiries showed that the Germans had pursued an almost parallel development of the turbo-jet engine. When Whittle started on his first engine, a young engineer named von Ohain began work on a similar engine for the Heinkel company. The Germans made a jet-engined plane which flew for ten minutes in August 1939, nearly two years before Whittle's E.28. This was the Heinkel He. 178. But apparently its development was dropped, for it was not heard of again. Its engine resembled Whittle's. It is not known whether the invention was independent, or whether it was inspired by the publication of Whittle's first patent in 1932.

In the last year of the war the Germans made intense efforts to develop a variety of jet planes, in order to intercept the devastating Allied bomber raids. Because of their lack of suitable materials, their jet-engines were inferior in performance and durability, but by sacrificing safety factors, very high speeds were obtained in intercepting fighters. On one occasion, thirty-two out of a formation of thirty-six American bombers were brought down by them.

Shortly after the publication of details of the British turbo-jet engine, Sir Stafford Cripps, who was then Minister of Aircraft Production, announced that the Power Jets Company was to be nationalized. Whittle had some time before suggested to him, in a very impressive letter, that the whole jet-engine research, development, and industrial production should be nationalized. He explained that not one of the firms entering the field had taken any speculative risk, and his own Power Jets, which had done all the original invention and development, had not been allowed to enter the production field. The three leading experts on gas-turbines, H. Constant,

A. A. Griffith, and himself, were, or had been for most of their lives, Government servants. It would therefore be no change for them to work in Government service.

He estimated that the only private money yet spent on the development of the engine had been £23,000 found by Power Jets. The large sums spent by the big firms had virtually been provided by the Government through contracts.

Whittle was therefore astonished when he heard that Power Jets would be nationalized and converted into a state-owned gas-turbine experimental establishment, but that the big private firms making jet-engines would not be nationalized. When he protested that he considered this extremely unjust, Sir Stafford Cripps explained that the Government was not socialist, and in the situation then existing, nationalization of the big aircraft firms was politically quite impossible.

The Government purchased the assets of Power Jets for £135,563. Whittle's rights and shares were valued at £47,000. He refused to accept this, on the ground that he was a serving officer, and that he did not consider that it was consonant with his duty to accept profits from an invention used by his service.

The severe struggle over the one-sided nationalization of Power Jets, and his internal conflict over the surrender of his financial rights caused his health to deteriorate still further. He had to spend long periods in hospitals for treatment.

He became Chief Technical Adviser to the board of the newly nationalized company, but his contact with its work dwindled rapidly, because of his intense disagreement with the policy, and his ill-health.

Meanwhile, the new pattern of jet-engine development in Britain evolved rapidly. The nationalized company, which was presently transformed into the National Gas Turbine Establishment, was reorganized on scientific civil service lines. The inspired research team which had invented the turbo-jet engine was broken up. Its members, accustomed in their great days to work like engineering poets, were required to sign time-keeping books. Scientific civil servants of high talents but less genius were put in charge.

At the demand of the aircraft companies, the National Gas Turbine Establishment was excluded from designing and building even prototype engines. This had been defined as competing with industry.

It was evident that Whittle and his original colleagues, if they stayed in the new establishment, would be deprived of the right to design and make experimental engines for the new industry which they had invented.

Whittle thought that the election of the Labour Government in 1945 might have led to a more balanced relationship between the nationalized company and private industry, but this did not happen. In January 1946, he decided that he must resign from the board. The separation of research from production, through the restriction of research to the Government laboratory, and of production to private industry, destroyed the feature which he believed was essential for creative engineering invention. The team he had led and inspired were intensely interested in doing a practical job of work. They had wished to see their products used, and also had their use immediately in sight. They were not interested in research as an end in itself, but only as the means to obtain the knowledge by which the engine could be developed. Such a team requires a series of short-term visible objectives, and not a long-term programme whose outcome was incalculable and out of sight.

Whittle felt that his position was tragic. His team, which had founded the new industry, was being bludgeoned into ineffectiveness. Its members had trusted in his prestige to prevent the deterioration in their status, but this had failed. Under the new arrangements they were depressed and uninspired, and the spirit had gone out of them. Many of them felt that they had been deprived of their chief interest in life.

Whittle became more and more detached. He made several lecture tours in America and other countries, and had to return again to hospital for further treatment.

Meanwhile, honours were showered on him. In 1944 he had received the Ewing Medal of the Institution of Civil Engineers, and the Gold Medal of the Royal Aeronautical Society. In 1946 he received the Clayton Prize of the Institution of Mechanical Engineers. In the same year he received the Guggenheim Medal, and the rank of Commander in the Legion of Merit, in the United States. He received the Kelvin Medal in 1947, the Melchett Medal in 1949, and the Rumford Medal of the Royal Society in 1950. In 1951 he received the Gold Medal of the Federation Aeronautique International. In 1952 he received the Churchill Gold Medal of the Royal Society of Engineers, and the Albert Gold Medal of the Royal Society of Arts. He was elected a Fellow of the Royal Society in 1947.

In 1948 the Royal Commission on Awards to Inventors was requested by the Ministry of Supply to consider his case. It recommended that he should receive an award of £100,000 free of tax. On the following day H. M. Government announced its acceptance of the recommendation, and in a very short time Whittle duly received this sum.

Later in the year he was knighted, and shortly afterwards he retired from the Royal Air Force, on medical grounds, with the rank of Air Commodore.

So, by the age of forty-one, he had accomplished a revolution in power engineering, and had received many appropriate honours.

His withdrawal from the industry, and his insistence on matters of principle, at once suggest comparison with Orville Wright. It is very striking that these two major aviation pioneers should have reacted in a similar way to the environment of their time.

Whittle agreed to act as honorary adviser to the British Overseas Aircraft Corporation on the development and operation of gas-turbine aircraft, and as consultant to Power Jets (Research and Development) on all matters relating to gas-turbines, except in the field of civil aviation.

His general concern with the evolution of affairs in Britain was reflected in his acceptance of the chairmanship of the Council for a New Era of Emigration. In this connection, Whittle remarked that Britain was the most vulnerable country in the world to attack by atomic bombs and other new forms of weapons. The most potent weapon that could be used against her was starvation. The population of Britain was fifty million but the country could maintain only thirty million without imports of staple foods. There should be a mass emigration to the Dominions, where the density of population was only one fiftieth as much, and the populations were far too small to exploit the vast natural resources. With emigration to Canada, Australia and New Zealand at the rate of a million a year and more, it would be possible, given five years' grace, to obtain a much better distribution of population. The strength of the whole Commonwealth would be greatly increased, and thus, he thought, would help to avert another war.

However, events in Britain did not evolve as he had hoped. In 1952 he resigned his honorary advisership to the B.O.A.C. It became known that he was so dissatisfied with developments in Britain that he was considering continuing his researches in other countries. Mr Dudley Williams M.P. referring in the House of Commons to his resignation from the B.O.A.C., said that 'it was curious that Sir Frank Whittle should be pushed out of the organization and not allowed to see his plans fulfilled'.

Whittle now turned to another field, and made an important contribution of a different kind. He wrote a carefully documented account of his invention, and his struggles to develop it and found the jet-engine industry. He published this in his book, *Jet: The Story of a Pioneer*, in 1953. It is based on very full records of minutes of meetings, letters, careful notes of telephone conversations, and even of luncheon-table conversations.

He wrote the book as a cathartic to relieve his mind of the conflicts caused by his struggles, and to describe the kind of seed and soil from which inventions spring.

In January 1954, it was announced that Whittle had become adviser to the oil company, the Bataafsche Petroleum Maatschappij, whose headquarters are at The Hague, in Holland. He would deal with the mechanical engineering aspects of the development of techniques and equipment in the petroleum industry, both in the handling and refining of petroleum, and also in the new chemical industries based on petroleum as their raw material.

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